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NATIONAL AVIATION UNIVERSITY
Faculty of Transport, Management and Logistics
Air Transportation Management Department

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“______”________________ 2020

MASTER THESIS
(EXPLANATORY NOTES)

Theme: “Technology of passengers waiting time decreasing in the airport”

Done by: Mohammed Maghraoui
Supervisor: Professor, D.Sci. G. Yun
Standards Inspector: Yulia V. Shevchenko

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Kyiv 2020

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
Факультет транспорту, менеджменту і логістики
Кафедра організації авіаційних перевезень

ДОПУСТИТИ ДО ЗАХИСТУ
завідувач кафедри
_____________________ Юн Г.М.
«______»______________ 2020 р.

ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ
«МАГІСТР»

Тема: « Технології зменшення часу очікування пасажирів в аеропорту »

Виконавець: Мохаммед М.

Керівник: д.т.н., професор Юн Г.М.

Нормоконтролер: Шевченко Юлія Вікторівна

Київ 2020

NATIONAL AVIATION UNIVERSITY

Faculty of Transport, Management and Logistics

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Major: 275”Transport Technologies”

APPROVED BY
Head of the Department
____________________ Yun G.M.
“______”_________________2020

TASK

of completion the master thesis

Mohammed Maghraoui

1. Theme of the master thesis entitled “Technologies for reducing the waiting time for passengers in airport” was approved by a decree of the Rector order № 2401/st. Of 17.10.2019.

2. Term performance of thesis: from 14 October 2019 to 29 December 2019 and from 20 January 2020 to 09 February 2020.

2. Initial data required for writing the master thesis: innovative passenger handling technologies, statistical data of passenger traffic volumes at Casablanca Mohamed V International Airport in 2010-2018, statistical data of cargo traffic volumes at Casablanca Mohamed V International Airport in 2005-2018, cost of development, implementation and maintenance of queue management system components, average processing time of passenger service and average passenger waiting time in queues in Casablanca Mohamed V International Airport.

3. Content of the explanatory notes: abstract, contents, notation list, introduction, theoretical part (queue management theoretical basis), analytical part (general characteristics of Casablanca Mohamed V International Airport, the airport statistical data analysis), design part (theoretical queue management description calculation of total development, implementation and technical support costs of the

queue management system and application for Casablanca Mohamed V International Airport and the ways of time efficiency improvement assessment using queue management system implementation the in Casablanca Mohamed V International Airport), conclusions, references.

4. List of mandatory graphic matters: diagrams or graphs of Casablanca Mohamed V International Airport passenger traffic volumes in 2010-2018, cargo traffic volumes in 2005-2018, comparison these statistical data with the same statistical data of the Kyiv Boryspyl airport; comparison of two cost scenarios of development, implementation and maintenance of the queue management system; and application for Casablanca Mohamed V International Airport and time efficiency improvement assessment from queue management system implementation at Casablanca Mohamed V International Airport.

5. Planning calendar

№	Assignment	Deadline for completion	Mark on completion
1.	Collection and processing of statistical data	17.10.19 – 31.10.19	done
2.	Writing of the analytical part	01.11.19 – 14.11.19	done
3.	Writing of the design part	15.11.19 – 30.11.19	done
4.	Writing of the introduction and summary	01.12.19 – 14.12.19	done
5.	Execution of the explanatory note, graphic matters and the presentation	15.12.19 – 20.12.19	done

7. Given date of the task: january 20.2020

Supervisor of the master thesis: ____________ G. Yun

Task was accepted for completion: _____________ Mohammed Maghraoui

ABSTRACT

Explanatory note to the diploma project “Forecast of introducing innovative technologies of airport passenger handling”: 116 pages, 34 figures, 15 tables, 32 equations and 24 references.

Key words: AIRPORTS MANAGEMENT, WAITING TIME, SECURITY CHECKPOINT MANAGEMENT, SEMI-MARKOVIAN QUEUEING MODEL, M/M/C QUEUE.

The research is devoted to development, implementation and technical support of the queue management system for Casablanca Mohamed V International Airport.

The object of research. Mohammed V International Airport in Casablanca, Morocco.

The subject of research. Queue management process improvement in Mohammed V International Airport in Casablanca, Morocco with the help of Queue Management System.

The aims and objectives of the research. The aim is to improve time efficiency from Queue Management System implementation at Mohammed V International Airport in Casablanca, Morocco for passengers queue management.

To achieve the aim during performing, it is necessary to perform a number of tasks:

– analyze queuing theory, queue mathematical models and choose one for implementation in queue management system;
– collect and analyze passenger traffic and cargo volume statistical data of Mohammed V International Airport in Casablanca and Boryspil International Airport in Kyiv Ukraine for comparation;
– determine hardware and software components of the queue management system, calculation of total development, implementation and maintenance costs of the system for Mohammed V International Airport in Casablanca based on minimum and maximum cost scenarios;
– assessment of time efficiency improvement from queue management system implementation at Mohammed V International Airport in Casablanca based on average passenger service rates for one or more control stations.

The techniques presented in this research can be easily adapted for other airports with minimal changes.

CONTENTS

NOTATION LIST

IATA – International Air Transport Association

IoT – Internet of Things

SDK – software development kit

PN – Passenger Number

WT – waiting time

PT – processing time

DMV – department of motor vehicles

AO – Airport Operators

JIT – Just-In-Time

CFM – Customer Flow Management

QMS – queue management system

SCC – Security Control Counters

FCFS – First Come First Served

CCP – Congestion Control Policy

OCC – Operational Control Center

QCM – Queueing Control Module

RMS – Resource Management System

INTRODUCTION

Air Transportation Management Department				NAU 20. 09. 46. 001EN					
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Head of the Dep.	Yun G.								

Currently, one of the main issue for both Airport Operators and Passengers is to provide a quick access to the Airport facilities and to prevent congestion during peak periods. Towards this end, this work proposes an integrated service hardware and software platform, that aims at enhancing both the airport management efficiency and the travel experience. Through the use of an analytical approach based on the queueing theory, the proposed platform is able to carefully forecast the waiting time at the security desks as well the required the number of active Security Control Counters, in order to improve the overall efficiency. The accuracy of the obtained analytical predictions has been validated by comparisons with real data obtained from a measuring campaign carried out in an airport environment. Based on the obtained results, the proposed platform can be considered as a practical support to achieve an efficient resource airport management and to improve the passengers Quality of Experience.

Nowadays, an airport represents one of the largest and most technologically advanced man-made system. Furthermore, the economic relevance of international air transportation is becoming increasingly important in response to the growth of the market demand. One of the main aspects to be addressed in designing an efficient airport system is to assure to customers (usually referred to as passengers) a fast access to the facilities, with the aim at mitigating congestion during peak periods. Towards this end, (i) check-in and (ii) security screening procedures represent critical activities both from the airport operators and passengers point of view Gillen and Morrison (2015).

Online check-in, joined with self-service kiosks, represents an effective approach to reduce the peak check-in waiting time Ma et al. (2011). Conversely, there are no out-off-the-shelf optimal solutions for security controls, which are typically implemented through: walk-through metal detector, hand-held metal detector, body scanner, dogs and manual inspections. Hence, in order to prevent that a long waiting time at the security desk could have a negative effect on the passengers' satisfaction Kirschenbaum (2013), Airport Operators (AOs) are requested to identify efficient techniques and systems.

The topicality of the research. Nowadays, an airport represents one of the largest and most technologically advanced man-made system. Furthermore, the economic relevance of international air transportation is becoming increasingly important in response to the growth of the market demand. One of the main aspects to be addressed in designing an efficient airport system is to assure to customers (usually referred to as passengers) a fast access to the facilities, with the aim at mitigating congestion during peak periods.

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1. THEORETICAL PART

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1.1. Queue management: Elimination, expectation, and enhancement

Abstract Queues in a service process represent an unmet customer need and can detract from the value an organization provides. In this article, we present a framework based on three principles for managing customer queues to reduce the discomfort experienced while waiting: (1) eliminate or reduce the wait through process enhancements, (2) manage expectations through timely and relevant communication with one's customers, and (3) enhance the waiting experience. We provide examples of historical and recent innovations along all three dimensions in multiple situations and suggest practical approaches for managers to add additional value to customers while they wait.

A queue can be found anywhere there is demand for a good or service that temporarily and locally outstrips the ability of the provider to meet the demand; a queue represents a customer need that is going unmet. Queues grow due to variability in arrival patterns and service times, and long lines may frustrate customers and cause them to seek service elsewhere. Note the quote from the American baseball player and oft-quoted philosopher, Yogi Berra: "Nobody goes there anymore. It is too crowded." Managers often must increase their costs by providing additional service capabilities to address the major causes of customer waiting times: high utilization and excessive variability. Thus, traditional approaches to queue management are either to (1) accept waiting time as unavoidable, (2) add capacity to lower utilization, or (3) attempt to reduce variability. Each approach is costly in one way or another.

Whether it is at a theme park or the department of motor vehicles (DMV), the butcher counter or the grocery checkout counter, on the road or on the phone, waiting for your turn is a part of life. Queues are often connoted negatively in the public's mind, being associated with the bread lines of the Great Depression, collapsing governments (e.g., 1917 Russia), and other various crises and disasters. Poland's Institute of National Remembrance released the board game Kolejka on the theme; the game is played by standing in line for the necessities on your shopping list while other players with a Colleague In The Government card can cut in front of you (Petzinger, 2011). Line waiting can be so onerous for some that they even hire people to do it for them (Elkins, 2015). Long queues can occasionally have positive associations, as with the arrival of a new electronic gadget, a movie, or a book, though the positive association almost certainly does not come from any joy intrinsic to the act of queueing itself. Long queues can sometimes enhance the cachet of a luxury good or exclusive service such as a nightclub, where being seen in the queue is itself a Veblen good. The draw for upmarket streetwear provider Supreme is as much about the wait in line as the merchandise (La Ferla, 2017); as the Washingtonian reports (Schaffer, 2017), "Waiting in Ridiculously Long Lines is Washington's Latest Status Symbol."

A Los Angeles Times article suggested that 5 years of the average American's life is spent waiting in line (Smith, 1989) and while other research (Stone, 2012) puts the figure somewhat lower, the process is seldom pleasant. Stevenson (2012) suggested that three specific aspects of waiting in queues are sources of unpleasantness: boredom with the wait, unexpectedly long waits, and unfairness in the process. These aspects pertain, in part or in full, to the psychology of waiting rather than the efficiency of the operation itself, but the operations manager ignores human factors at his/her peril.

Basic operations-management principles can easily address issues of fairness: form one line instead of many; apply first-come, first-served principles (unless an express lane can be formed in a way that everyone finds fair); do not allow line jumping. Innovative approaches to queue management, though, can alleviate or reverse the boredom and manage expectations, making the process less painful for customers and frontline employees via three mechanisms: (1) eliminating or reducing the wait, (2) managing expectations, and (3) enhancing the experience.

Some of these innovations in queue management have been brought about by sheer creativity, with managers finding unexpected ways to solve an age-old problem. Many others, though, use emerging technologies to extend the older innovations in new ways, and even the creativity-challenged manager may find ways to apply them to his/her operation.

A framework for thinking about queue waiting times

In her article “Breaking the trade-off between efficiency and service,” Frances Frei (2006) addressed the issue of waiting in line through two techniques: accommodation and reduction. The managerial issue becomes one of determining how to accommodate variability, either in arrivals or in service, without increasing costs; or to reduce variability without compromising service. Consider Table 1 as an alternative framework. The idea here is that customers are dissatisfied when waits are longer than expected. The options are to modify the expectations, eliminate or reduce the wait, or enhance the experience so that the wait does not appear so long. Mathematical queueing models can help us predict wait times as functions of key parameters such as number of servers, the mean and variance of arrival rates and service times, and queue discipline. David Maister (1985) wrote about rules of perceived waiting. Judicious application of these rules allows management of both the expectation and the experience of waiting.

Historical queue-management innovations

Many people think of the single snake line as the first and oldest innovation in queue management. Rather than have multiple servers with multiple lines, a single line may be formed to feed multiple servers. This tactic reduces the number of unfair waits in which someone entering the system might skip over someone who arrived earlier. It also reduces the impact of service time variability.

An early innovation in queue management came in the 1950s. A story is told, perhaps apocryphally, of a Manhattan office building whose tenants complained to management about the wait for the elevators. Unable to add new elevators to the building or to increase the speed of the existing cars due to cost considerations, the building manager decided instead to install floor-to-ceiling mirrors in the lobby. The building’s tenants stopped complaining——not because their wait was any shorter, but because it felt shorter now that they had something to do while waiting.

A related story is told of an airport in Houston where passengers complained of long waits to collect their luggage from baggage claim, despite the measured service time falling well within industry benchmarks.

Going to the gemba, management discovered that passengers had a very short walk from their arrival gate to the carousel; thus, the passengers experienced nearly all the time needed to deliver the bags as waiting. Management resolved the complaint issue by relocating the arrival gates and baggage claim areas to opposite ends of the terminal. It took longer after the relocation for passengers to claim their bags than before, but with the waste of transportation (which some might view as a benefit rather than a cost) substituted for the waste of waiting, passengers were happier and complaints ceased (Stone, 2012).

Another older innovation is to make the wait more comfortable, if not necessarily more interesting. Since at least the dawn of the railroad industry, transit hubs have featured benches or chairs for people to sit on while they wait. Professional offices and luxury car dealerships have taken this idea further with leather armchairs, free coffee, and soothing music. Restaurants with ample space at the bar while one waits for a free table for dinner canal so be though to fas having adopted this innovation; not only are the diners kept more comfortable, but also the restaurant is able to make additional high-margin beverage sales.

Another early breakthrough in queue management was ticket-based queue management, which can be found at the deli counter ata supermarket. Unlike the checkout area, where a large amount of the store's floor space is devoted to providing an area for customers to arrange themselves in structured queues, the area around the deli counter is much smaller; deli customers arrive from all directions and some customers try to push past the throng at the counter to get to other departments. Rather than tie up the attention of the limited number of deli clerks with keeping track of who arrived first——or permitting unfair and therefore frustrating service in random order——as customers arrive, they take a numbered ticket that represents their position in a virtual queue. Customers can then mill about or continue shopping without anxiety or fear of unfairness, confident that their ticket holds their place in line. Analogous systems use electronic pagers or cell phones.

A fifth early innovation is implementing an appointment process. Queues arise when customer arrivals outpace the ability to provide service; by requiring appointments, customers only arrive at regularly spaced intervals when capacity is known to exist. Further, the waiting time in a queue increases with growing variability in customer arrival times (Weiss, 2013); by requiring customers to arrive only when you allow them to, this variability goes to zero, and the wait time is greatly reduced. If a good or service is in high enough demand and it is not required immediately, customers will acquiesce to the need to make a reservation. Unfortunately, this queue-management solution only works if the world is beating a path to your door. Moreover, this solution sends a message that may not fit within the marketing strategy of all businesses——namely, that the service provider’s time is more valuable than the customer’s.

A final, notable, early innovation in queue management is co-opting the customer to be part of the service-delivery system. In 1916, Clarence Saunders opened the world’s first self-serving store, in which customers could choose the goods they wanted to buy from a shelf, then pay a clerk at the front of the store (The Economist, 2015). His innovation, which we now know as the supermarket, was revolutionary in his day, and his invention was awarded U.S. Patent No. 1397824 in 1921. By allowing the customer to choose his/her wares rather than present a shopping list to a clerk and going to the source, or where the action is. It is part of the ‘lean’ lexicon. Lean emphasizes going and seeing rather than attempting to solve problems from the comfort of one’s office.

wait for the items to be gathered, Saunders’s Piggly Wiggly chain was able to, among other things, reduce the idle waiting time the customer experienced while making a purchase. Curbside pickup and home grocery delivery can be seen as a reversal of this innovation, to the detriment of some consumer categories (Harwell, 2015).

Approaches to expectations management

As we mentioned previously, the unpleasantness associated with waiting in a queue derives in part from waits that are unexpectedly long. Customers' anxiety can be relieved by providing realistic expectations of the anticipated wait time, then meeting or exceeding that expectation. A famous low-tech example of this idea is the sign age at the queues in Disney theme parks. In addition to aiding guests' decision-making process by keeping someone who needs to leave in an hour from getting in a 90-minute line , the Approximate Wait Time From Here signs are intentionally labeled slightly too high so that the average visitor is led to believe the queue for the theme park ride is moving more quickly than anticipated. The small satisfaction experienced as a result of the swiftly moving line enhances the guest's experience with the ride, and therefore with the company (Pawlowski, 2008).

A more high-tech approach to the same queue-management idea is employed with live highway signage. By letting drivers know of delays before they pass the last exit before the delay, commuters have the opportunity to bypass the obstruction and not only reduce their own travel time but also improve performance of the whole system. Even better than such messages as Emergency Roadwork, Expect Delays are signs that state the mileage and travel times to multiple destinations along a roadway, as these messages give motorists the magnitude of the delay and allow them to plan accordingly. If unexpectedly long queueing, rather than queueing itself, is a cause of frustration, such signs may help to keep tempers calm on congested motorways.

These queueing practices have also been adapted to the internet. On the Virginia DMV website, one can view the approximate wait time and the number of people already in the queue for each of the various services the DMV provides. Someone in a metropolitan area in Virginia can select the least-busy DMV within driving distance; someone with fewer offices in their vicinity can at least steel themselves for the wait. The INOVA system of hospitals in northern Virginia offers a similar service, letting prospective patients know the wait time at each of the 13 emergency rooms in the system. Hartsfield-Jackson International Airport in

Atlanta, Georgia, offers an e-mail information service it calls Trak-a-Line; this service sends automatic e-mail updates close to the subscriber's flight departure time with information on the queue times for the various security lines in the airport.

Systems such as these provide the customer with information to prepare themselves psychologically for waiting, and to avoid queues entirely when the wait is longer than they can afford. These two mechanisms work in tandem to make customers happier and to shunt away customers who would become displeased with the operation. A potential downside is that with the promise of a short wait having been made, if something goes wrong to make the wait time longer than expected, the customer may be more displeased with the outcome than if no promise had been made. A definite upside is that customers can redirect themselves to underutilized capacity within the system, balancing the load and improving system performance as if the system had reactive capacity at the ready.

Approaches to eliminate waiting

One category of innovative queue management is using technology to eliminate processes that require the customer to wait. From an operations perspective, this could be viewed as just another important than that. Waiting in a queue is a pain point for one's customers, and addressing the root cause of the queue can be a fruitful target for waste-reduction efforts.

One way to eliminate waiting times is to schedule an appointment or place in line prior to arriving at the point of service. Depending on the specific method by which it is applied, it can be thought of as taking a number before arriving at the service counter, or as making an appointment or reservation for a service that is traditionally unscheduled. Call-ahead seating——getting one's party in line for a restaurant table prior to arriving at the restaurant——was an early, low-tech application of this technique, but the ubiquity of the internet and connected mobile devices has permitted many more applications.

The Sentara Healthcare system of medical care facilities in Virginia and North Carolina offers online scheduling for emergency room visits. Online scheduling of medical appointments is not——in 2017——a groundbreaking innovation, but Muda is the Japanese word for waste, or non-value-added activities. Wait is one of the seven classic forms of Muda: the other six are transport, inventory, motion, overprocessing, overproduction, and defects.

its application to emergency care may be. The web-based system is simple to use and requests little more than the patient's name, birth date, and reason for visit——simplicity that may be necessary when considering the user of the system is a person in need of urgent medical attention. Emergency care can be scheduled within an hour of the visit to the website, and the patient can wait their turn at home rather than in the lobby.

Another unexpected application of virtual queueing to eliminate waiting is in theme park rides. In 1999, The Walt Disney Company introduced the FASTPASS system at some of its theme parks. With this system, park visitors could request a ticket to board a certain ride at a certain time of day; upon their return at that time, they would be moved to the front of the queue to board the ride (Martin & Poston, 2017). A competing theme park, Universal Studios Florida, extended the concept, allowing visitors to check into its new Race Through New York Starring Jimmy Fallon attraction using the theme park's app (ICFlorida, 2017).

A more mundane application of the same concept is virtual queueing at call centers. Rather than wait on hold for an operator to become available, the caller can request a call back from the call center. Depending on the implementation, the customer can receive a callback when it would have been his/her turn on hold, or at a later scheduled time and date. The first implementation, from the customer's perspective, turns waiting on the phone to waiting by the phone; in the modern age of wireless technology, that prospect is more pleasant than it was just a few decades ago. The second implementation, from the call center's perspective, turns an unscheduled arrival that must be predicted into a scheduled arrival that can be planned for. Sophisticated call-center-management software may also divert calls to entirely different locations if the anticipated waiting time is deemed too long.

Automated teller machines (ATMs), versions of which first appeared in 1967 (Rodriguez McRobbie, 2015), are an early example of technology eliminating the need to queue. In a world without ATMs, customers had to visit a bank branch during business hours and wait in line for a teller to perform such transactions as cash withdrawals and check deposits. With the introduction of ATMs, customers were freed not only from queueing in teller lines but also limited banking hours; the 1978 blizzard that shut down New York City played a major role in earning popular acceptance of the devices (PYMNTS, 2015).

Other uses of technology to eliminate queueing include fax-ahead, call-ahead, and internet-based ordering. When these technologies are used in retail stores and restaurants, they can eliminate queueing for the customer as the processing time to make the food or assemble the goods being purchased can take place while the customer is on the way to the store. In other implementations——such as fax-ahead ordering or app-based ordering at Chipotle and Starbucks——though, this innovation can have a downside. In a busy restaurant with only a single channel for order delivery (i.e., one burrito assembly line or one barista), customers in the store queue must wait longer while the order-ahead meal or drink is assembled; the technology does not shorten the queue on average; it merely changes who must wait in it. The 400-restaurant chain McAllister's Deli found that its mobile-ordering customers felt they had to wait in the customer queue to pick up their to-go orders; in response, McAllister's instituted cubbies for mobile-order pickup, thus shortening the wait for those customers and lessening the appearance of wait for other in-store patrons (Jargon, 2017).

A new system introduced at Domino's Pizza restaurants in India takes the idea further. Partnering with Nuance Communications, Domino's implemented a natural-language-processing automated telephone service for placing orders. The customer can place their order in a conversation with a computer system in English or Hindi, and the system converts the conversation into an order for pizza (Link, 2017). The customer does not have to wait while their call is routed to a human, so there is never a queue to reach a live operator. Meanwhile, in the restaurant, the employees do not need to stop what they are doing to answer the phone, potentially leading to faster service for customers queued in the store.

Also in the food-service industry, touch screen-based ordering is gaining traction as a means to eliminate the need for some queueing. The midAtlantic convenience store chain Sheetz was an early adopter of touch-based ordering, having introduced such a system for its made-to-order food offerings in 1996 (Phelps, 2016). In 2015, McDonald's began introducing touch-screen ordering in its stores, converting standing in a queue at the counter to waiting seated at a table for a meal to be delivered (Peterson, 2015). In the same year, San Francisco-based quinoa chain Eatsa launched with an extension of the touch-screen concept: having no cashier or other visible employees at all, with cooked meals being placed in cubbies for customer pickup. The only queueing with the concept is in the wait for the meal to be assembled (Schneider, 2015). Not only do such systems reduce queueing and increase accuracy, but they also can increase the per-customer revenue for restaurants that implement them (Krystal, 2017).

Similar queue-reducing innovations are being introduced in the beverage-service industry. Bars can install self-service beer and wine taps that use nearfield communication bracelets (Edelen, 2015) or RFID cards (Pour My Beer, 2018) to charge customers by the ounce poured. Customers can get their next drink without queueing for the bartender's attention, and indecisive tasters can get multiple small samples without slowing down the operation.

Approaches to enhance the waiting experience

If a queue is unavoidable, a better outcome for both the customer and the firm can be achieved by making the queue part of the service process rather than merely a prelude to it. An author of this article was confronted with a 2-hour line to vote in the 2012 U.S. general election. An election official went through the queue with a device to check voter registration of the citizens in line to ensure that, after waiting for 2 hours, they did not find they were at the wrong polling station.

Customers of retail stores——supermarkets, most notably——may notice that the checkout lines are flanked with high-margin, low-dollar-value items (e.g., candy, tabloids) in attractive displays to encourage impulse purchases or, at a minimum, to distract customers from their wait in line (Nathanson, 2013). The checkout queue, from a merchandising perspective, is another aisle and another opportunity to drive revenue.

Customers waiting in a queue can also be a receptive audience for increased brand engagement. Starbucks partnered with music-streaming service Spotify to allow Starbucks rewards members to discover the music being played in its stores, and to have access to that playlist even after exiting the store (Starbucks, 2018). In the past, Starbucks offered free downloads of a selected app, book, or song to customers visiting the store (Clay, 2012). Under this strategy, captive audience members in store queues find a way to pass the time and continue engagement with Starbucks long after leaving the store.

Walt Disney World Resorts are exemplars of turning queue waits into entertainment experiences. At Disney, the queue is thought of as part of the attraction (Pawlowski, 2008) and is often, at a minimum, decorated as such; for example, the queue area for an Indiana Jones ride looks like an archaeological dig, while a Star Wars-theme dride looks like the inside of a starship, building anticipation for the ride itself while distracting from the wait. The queue for a Toy Story themed attraction at a Disney park in California features an animatronic Mr. Potato Head voiced by comedian Don Rickles, and, in addition to prerecorded jokes, some queues feature interactive entertainment. Perhaps the most outstanding innovation yet has been employed at the Dumbo the Flying Elephant ride, where the waiting happens in an air-conditioned tent full of playground equipment, and a pager buzzes guests when it is their turn to ride (Martin, 2013).

Many retailers find it worthwhile to offer free product samples (Reyhle, 2015); some retailers provide these samples to customers waiting in line. Queued customers appreciate the gesture, as it seems like a reward for having to wait. In addition to the good will it can generate, in some circumstances it can make more sense to provide samples to customers in line as opposed to offering the same samples elsewhere in the retail experience. While all customers pass through the checkout point, not all customers might notice a similar promotion elsewhere in the store, particularly in a large-format retail environment like a supermarket. Providing samples to queued customers may also provide a low-risk way to test new product lines. Stacy's Pita Chips (Morell, 2012), a prepared snack company, started as a small sandwich food cart. The proprietor, Stacy Madison, distributed baked, leftover pita bread from the previous day to customers waiting in line for sandwiches, as an incentive to stay in line (Stacy's, 2018). The pita chips became more popular than the sandwiches, leading Stacy to close her food cart and launch a snack food company, which she eventually sold to PepsiCo.

Customers may experience queues waiting for your business to serve them. A manager should periodically review the processes in his/her purview to identify customer queues and evaluate the experience customers have while waiting in them. Note that queues may not be physically manifested if, for instance, clients wait in a sales department for a quote or in a production department for a custom order. Take stock of how long customers wait, and how they experience the wait. Make sure they know their place in line is being held and that they receive realistic and timely updates on when they can expect to be served. Finally, examine whether your firm can take a creative approach to manage customer expectations, eliminate the wait, or enhance the experience.

A design shop working on a custom order can manage customer expectations by switching to more customer design reviews with shorter periods in between. Rather than endure one long wait, the customer will experience several shorter, and therefore more pleasant, waits. The increased interaction between the customer and the design staff will increase customer satisfaction with and ownership of the finished design and will give your employees the opportunity to build enduring relationships with your customers.

Any business can benefit from the use of Lean principles to minimize waiting time in customer facing processes. A bank lending operation can target its training programs and streamline its information technology systems to ensure that the data collected by loan officers is in the precise format needed by the underwriters. If all of the necessary information is collected correctly the first time and presented to the underwriters in the proper format, the loan decision can be made more quickly.

Enhancing the customer experience while waiting may be the easiest and least costly method for queue management, providing the quickest return on investment. A business whose customers endure waits on hold on the telephone can ensure that the hold music is tasteful and soothing, and does not sound shrill or harsh when played through the phone system. The manager of a professional service firm's office should verify that the seating and lighting in the waiting area are appropriate and adequate, that entertainment and refreshments provided send the right message, and that everyone is greeted swiftly and convincingly upon arrival. You can find specific ideas for enhancement by viewing your service processes through the eyes of your customers, for example, by calling your own phone tree or waiting in your lobby yourself.

By adopting innovative approaches to queue management, firms can find new opportunities to add value and improve customer brand perception. An unexpected, unexplained wait in uncomfortable conditions can sour a customer relationship; a firm that is mindful of its customers' needs and respectful of their time has an opportunity to improve its standing through thoughtful, creative approaches to queueing. Many opportunities exist to enhance the customer experience by managing customer expectations, replacing queues with appointments, eliminating queues entirely, or adding value during the wait.

1.2. Queueing theory and operations management

Waiting is an intimate dimension of our daily lives. Everyone has experienced waiting in line at the supermarket, the bank and any number of other places. We constantly observe traffic, hospital or court congestion, customers or machines are waiting and we experience waiting times for almost every service offered. These waiting-line situations are also called queueing problems. The common characteristic is that a number of physical entities (the arrivals) are attempting to receive service from limited facilities (the servers) and as a consequence the arrivals must sometimes wait in line for their turn to be served. Numerous applications are described and the mathematics of queueing has advanced tremendously over the last 40 years. The objective of this paper is to focus on operations management applications of queueing theory. The first textbook on the subject: "Queues, Inventories and Maintenance" was written in 1958 by Morse. A tremendous number of queueing problems occur in production and inventory management. Think of the design of facility layouts, staffing decisions, maintenance problems, the physical capacity problem, lead time estimation and lot sizing decisions to mention only a few. Over the last decade Just-In-Time (JIT), Time Based Competition and the Fast Cycle Time strategies gave rise to a renewed interest in queueing. Indeed, a Fast Cycle Time strategy is basically dealing with time, with reduced waiting times and an emphasis on a fast Time-to-

Market. It is amazing to realize that with a little understanding of how queues behave, the solution to many operations management problems becomes clear if not obvious. The paper is organized as follows. We select three major problem areas in operations management: the inventory-capacity trade-off, the impact of uncertainty (disruptions, variability) and capacity utilization on lead time and the impact of lot-sizing on lead times. We show how insights from queueing theory may be helpful to better manage these issues. It is tempting to treat the subject mathematically, but we opt in this article for a more qualitative approach. The enthusiastic reader however may not underestimate the mathematical intricacies involved.

Insights from queueing theory

A. The Capacity-Inventory Trade-Off

In order to better understand the capacity-inventory trade-off, it is important to understand the nature of the Just-In-Time (JIT) revolution.

The JIT Revolution can be summarized as follows (Zangwill(1992)): "The old viewpoint: Increase inventory, hold a lot in stock, and then you are ready for anything. The new viewpoint: Reduce inventory, cut the production lead time and you call respond fast to anything. These are two opposing views about being responsive to the customer". In the first case companies satisfy customer orders from stock, which is an immediate response. In a JIT environment companies satisfy customer demands with a certain time delay, which of course is kept as small as possible. We view the company more as a queueing system instead of an inventory system. Behind this new viewpoint focusing on a fast response, there is a synergetic chain of manufacturing changes that goes several layers deep. A successful implementation depends on the ability to eliminate all forms of waste, continuous improvement, employee involvement, disciplined implementation, supplier participation, reorganization of the production floor, modular designs, cell layouts, process control and total quality creation. The objective is to improve productivity. Moreover, through this fast response to specific customer needs, it is hoped that it results in an enhanced market power. The improved productivity and the stronger market position are supposed to be the basis for a sustainable competitive advantage.

The question now is: how can we guarantee a fast response with- out the protection of inventory as JIT asks us to do?

In order to answer this question, let's turn to a basic insight from queueing theory. It is well known that companies that try to operate with tight capacity are forced to carry substantial inventories to protect against unexpected surges in demand and other contingencies (Zipkin (1991)). High levels of capacity utilization cause increased congestion, longer lead times and higher inventories due to uncertain- ty. So if a company wants to reduce lead times or lower the inventories then it is advisable to have excess capacity. That's the inventory-capacity trade-off. We quote from Zipkin (1991), "Indeed, companies often find that JIT means buying more and better equipment - a serious commitment of capital resources".

In today's manufacturing environment companies are stressing due- date performance, time (cycle time, response time, time-to-market) and reduced inventory levels as primary measures of shop performance. In order to achieve this, companies seek to add capacity cushions in an attempt to become more responsive to customer demands (instead of inventory buffers). This of course is contrary to the traditional performance measure of resource efficiency (high levels of machine utilization). The core problem is the evaluation of the benefits associated with lower inventories versus the lower efficiencies associated with excess capacity. The question is whether a company is better off by replacing inventory by capacity, or by keeping the machine assets tight and accepting more inventory.

In order to have some empirical evidence of this phenomenon we analyzed the inventory position and the capital investments in the Belgian metal working industry in the period 1977-1991. Over this period the inventory position measured as work-in-process and finished product inventory relative to value added dropped from 50% to 31%. The investments in material fixed assets relative to value added in- creased from 32 % to 42 %. Another interesting observation is the following. In the period 1977-1991 total sales in the Belgian industry increased roughly by 300 % (including inflation and taking 1977 as the reference year). Over the same period depreciation charges increased by 420 %.

The decrease in inventory is of course not only attributable to the capacity expansion. A period of economic growth e.g. is always associated with a period of inventory depletion. It is also known that investments in automation and flexible equipment are larger than the required investments for conventional machinery.

The positive side of the coin is that the increased capital intensity positively contribute to the employee's productivity and that reductions in inventory also help to improve worker productivity. How can reducing inventories improve productivity? One possible mechanism is the dynamic learning process, inventory reduction helps to achieve a higher learning rate through a clearer exposition and easier identification of problems. (Kim (1993)).

There is however also a major drawback associated with the above-mentioned redistribution phenomenon. The question is what happens to companies that heavily invested in plant and equipment and that are confronted with a period of economic recession? The drop in demand, the entrance of many new competitors; and the heavy in- vestment boom created in many industries huge overcapacities, prices dropped, profits disappeared. We again experience a period of intensified price competition (cost cutting programs).

Don't forget that one of the premises of the JIT, Time-based philosophy was the prospect of achieving competitive advantage, higher margins (premiums) and more attractive profits. Now it turns out that excess capacity is an element of rigidity, a source of additional riskiness that may result in more variability of performance.

Is there a solution to this problem? Let us therefore go back to queueing theory. There we learn that variability and uncertainty are the key parameters. The more uncertainty, the more damaging high levels of machine utilizations are on inventories and lead time. We expect in other words lower levels of capacity utilization (more excess capacity) in job-shop manufacturing (e.g. machine building) compared to the more standardized manufacturing environments (e.g. consumer electronics). The argument is that the greater the uncertainty (e.g. in the receipt of customer orders), the higher the negative impact of increased congestion on inventories and lead times. We in- deed observe a 10 % point difference in average utilization between the industrial product sector (72 %) and the consumer product sec- tor (82 %) of the Belgian metalworking industry (period 1981-1992).

Every effort to reduce the level of variability (process control, zero defects, better supplier relationships, better forecasting, ...) will automatically have a positive impact on inventories. The process of continuous improvement is one of the only ways out to escape from the inventory-capacity conflict, which is basically a conflict between flexibility (responsiveness) and efficiency. Every inventory reduction program should be backed up by efforts of continuous improvement and better capacity management.

So the key to the solution is fighting disruptions caused by process instability and all sorts of unreliabilities. Disruptions lead to unnecessary high capital costs. Fighting disruptions is a learning process offering a clear target for human resources management. Ultimately 'people' implement strategies. Participative management combined with self-directed teams emphasizing joint problem solving and team work, total productive maintenance based on responsibility at the source are all means to achieve the objective.

B. Impact of Disruptors and Capacity Utilization on Lead Time

The fast cycle strategy and the associated crusade for lower inventories are based on the best known relationship of queueing theory: Little's Law. For simplicity, assume a single server queuing model with an arrival and processing rate of 1 and p customers per time unit. Under steady state conditions, Little's Law combines the two most important operations management performance measures into one formula: the average number of customers in the system, E(L) (equivalent to the average inventory) and the average time units spend in the system, E(W) (equivalent to average lead time).

$$\text{Little's Law: } E(E) = L.E(W)$$

Little's Law which is quite general and applies to any queue discipline specifies how inventory and time in the system are linked. A system containing a lot of inventory inevitably results in long lead times or, conversely reduce inventory and respond fast. The lead time, de- fined as the total elapsed time from order arrival until the order is finished and the customer is served, consists of two important parts: the waiting time and the processing time. The latter is mostly a fairly stable component of lead time. The average waiting time however is highly sensitive to system conditions such as the level of uncertainty and the capacity utilization. Utilization (p) is defined as the ratio of input rate to processing rate:

$$\rho=\lambda/\mu$$

Based on this, one can quantify quite easily the impact of uncertainty and utilization on average lead time. In general one can state that higher utilizations and / or higher levels of uncertainty cause longer waiting times and consequently lager lead time and higher levels of inventory. This in turn induces strategies to improve performance. One possibility e.g. is to consider capacity expansion another is to reduce the uncertain- ty in the system by eliminating all disruptions. This can be accomplished by automation, a better trained work force, standardization of processes, more design efforts, improved maintenance practices, quality improvements or in general all efforts related to continuous improvement. A careful analysis of the Japanese Production System immediately reveals that it is based on a combination of both above- mentioned strategies.

An exact quantification of the impact for more general situations (multiple machines at a workcenter, multiple part types, different routing, lot sizes, rework and other feedback loops, interdependencies, ...) requires of course an in depth mathematical treatment. Most steady state relationships for queueing networks are these days made available in commercial software packages. These software packages capture the main dynamics of the production system in a set of mathematical equations, which are next solved so that the system performance can be obtained with amazingly little computer time. This analytical approach can be viewed as a valuable alternative to the more traditional simulation approach The analytic approach brings the mathematics of queueing is reach of management who can use it as a dialogue tool to evaluate various strategic options. Examples of commercially available software packages are MPX (Network Dynamics) and QNA (Queueing Network Analyzer, Whitt (1983)).

To fit comfortably as a manufacturing model, a queueing model still exhibits a serious disadvantage. For many queueing systems, means are known but little else. In other words it is possible to express queueing behavior by means of averages (average inventory, average lead time,...). Knowledge of the average lead time alone is insufficient, what is also needed is the variance. Indeed, the variability of the lead time deter- mines to a large extend the probability of meeting quoted or promised lead times. In an inventory driven system demand and production uncertainties are protected by safety stocks, in a fast cycle time approach the protection is based on a safety time. The safety time can be quantified by means of a multiplier. The question is by what factor do we have to multiply the average lead time so that a quoted lead time is met X % of the time. Traditional inventory theory is mainly concerned with fixing order quantities and safety stocks. The new approach is concerned with quoting reliable lead times and consequently requires a safety time protection. In many cases the issue is not to quote a lead time but to satisfy a market imposed lead time.

It is clear that more safety time will be needed the larger the variability of the lead time. Moreover, the level of capacity utilization is also very important. Higher levels of utilization cause higher lead time variances and service levels will deteriorate. The congestion phenomenon (utilization and uncertainty) is again the key to any lead time reduction program. See Lamhrecht, Chaoxiang and Vandaele (1994) for a more detailed discussion.

C. Lot Sizing and Lend Times

Another key variable that impacts the lead time is the lot sizing decision. The lot sizing decision is probably the most intensively researched issue in operations management. The traditional approach focuses on balancing ordering costs and inventory holding costs. Since the advent of time-based strategies attention was turned to analyzing the impact of lot sizing on lead time. Traditionally the lead time was held constant, the objective now is to replace the deterministically assumed lead time by a stochastic lead time as a function of the lot size, uncertainty, capacity utilization and other parameters. The determination of this stochastic lead time is based on queueing theory and has been analyzed by Banker et al. (1988), Williams (1984), Zipkill (1986) and Wein ((1990), (1992)). Amazingly enough this relationship has been misinterpreted by many researchers and practicioneers. The reasoning goes as follows: Large lot sizes will lengthen the lead time and small lot sizes will automatically result in short lead times. This is wrong. Queueing theory will keep us on the right path. The rationale goes as follows: for a given setup time, some portion of the available time at a production facility will be spend on performing setups. Total setup time depends of course on the lot size. A small lot size results in a larger proportion of setup time and the capacity utilization of the production facility will increase. So, by manupilating the lot size the capacity utilization can be changed, and we know from the previous sections that utilization impacts the lead time. At this point it call be shown that two phenomena are present in the lot sizing decision: a batching effect and a congestion (saturation) effect. A large batch will cause a long lead time (batching effect), but on the other hand very small batches will increase the capacity utilization (the setup time portion), congestioil starts and consequently lead times will go up again. Both phenomena result in a con- vex relationship between lot size and average lead time. The conclusion is that both large and small lot sizes cause long average lead times. Analogous to the previous section it can be shown that the variance of the lead time is also a convex function of the lot size. Consequently, customer service will deteriorate both for very small or large lot sizes. It is interesting to note that exactly the same conclusion is reached in the traditional cost based approach, balancing holding costs and setup costs. In the queueing approach, we balance the batching and the congestion effect. Both approaches will however not result in the same optimal lot sizes. The full benefits of reduced batch sizes can only be obtained by reducing the level of uncertainty (disruptions), by maintaining a reasonable level of excess capacity or by reducing setup-times. The very popular setup-time reduction programs perfectly fit in this approach, it is an excellent way to realize continuous flow production, short lead times and high service levels. For more details see Karmarkar (1987). One of the recent developments in computer communication systems such as computer networks opened new perspectives for Iot sizing models. A common mode of operation for computer networks is e.g. polling. A polling model is a queuing model composed of a set of queues and a single server who visits the queues in a predetermined order. The data transfer from/in the terminals to the computer is controlled via a polling scheme in which the computer "polls" the terminals, requesting the data, one terminal at a time (Westrate (1992)). In such a situation it is important to know how long the computer serves the same terminal. The analogy with a lot sizing problem is obvious.

Most operations are stochastic because of uncertainty in the timing of customer orders or the receipt of purchased material and because of variability in the processing and set-up times caused by various disruptions. All this increases congestion and consequently inflates lead times and creates excess inventories. In a time- based production environment that's exactly what we want to avoid. So the basic question is how to handle congestion, how to take advantage of the trade-offs between various performance measures such as work-in-process, lead-times and investment in capacity. Insights from queueing theory are of great help here. A first strategy is to install some capacity in excess of expected de- mand. Indeed, capacity can be used to buffer the system against unexpected events (instead of the standard inventory buffers). This strategy is somewhat contrary to the traditional performance measure of resource efficiency. That's probably the reason why many companies are reluctant to have large amounts of standby capacity, after all, a large part of the Belgian industrial sector is highly focused on scale intensive activities (VEV, 1994). Instead of focusing on excess capacity it may be advisable to concentrate on a flexible use of the existing capacity (flexible working time schemes). This in turn offers a new incentive for increasing the use of flexible labor, both in terms of the number of people employed (numerical flexibility) and in terms of the mobility of employees to undertake a range of tasks (functional flexibility). A second strategy is to focus on uncertainty and variability reducing programs. Indeed, the most damaging factor in the pursue of a fast cycle strategy is the existence of all sorts of disruptions. Disruptions lead to congestion, it lowers the speed and it leads to high capital costs and inefficiencies all over. Process stability and reliability are obtained by quality and maintenance improving programs, by better designs and most importantly by installing a problem-solving attitude of all those involved in manufacturing. This is probably best obtained by focusing on small group activities in which learning and knowledge accumulation can result in an enhanced human competence and organizational commitment.

1.3. Queue Management Systems, Products and Best Practices

When gathered at events or commercial establishments, people generally expect that they may have wait in a line. Along with this acceptance, however, is the expectation that the line will be managed competently, and that patrons will be treated fairly.

Queue management (also known as line management) is an established business practice and, to handle it properly, sites need not reinvent the wheel. There are established processes and commonly-used tools which are widely accepted.

There are significant downsides to ignoring the ramifications of poorly-executed line management. The death of a Wal-Mart employee due to a stampede by shoppers on “Black Friday” in November 2008 brought the subject of line management to the national headlines.

A site or event with poor line management can create unhappy patrons which can result in potential lost business. But, more significantly, if these patrons’ attitudes move beyond unhappiness into anger or rage, crowd management problems could result in negative publicity or even, in extreme cases, public scenes which could result in unrest, physical danger, and lawsuits.

Line Management Psychology

Queuing psychology – the study of improving the experience of people waiting in lines – has been researched for over three decades. The landmark paper “The Psychology of Queuing and Social Justice,” by Dr. Richard Larson, was published in 1977. Larson, now the director of the Center for Engineering Systems Fundamentals at the Massachusetts Institute of Technology, has concluded that eliminating “empty time” in a line makes waits seem shorter, and that fair play (the concept of “first come, first served”) is the basis for most successful lines.

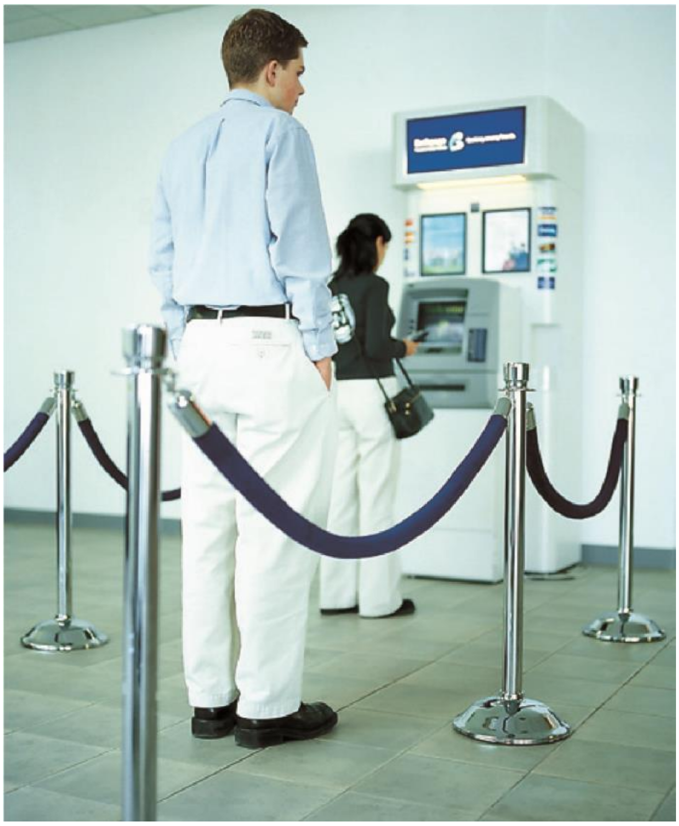

Fig. 1.1 First come, first served

As a result of queue psychology research, most banks, airlines, and fast food restaurants have changed their line philosophy since the late 1970s. Many had previously featured multiple lines in front of each employee (cashier, agent, teller, etc.), an arrangement in which patrons often ended up making the frustrating choice of a slow line. The "first come, first serve" serpentine line is now commonly accepted as the system which is more customer-friendly.

Disney's optimum queue management

According to the New York Times, "Disney World long ago turned the art of crowd control into a science." The Disney theme parks are viewed as a textbook example of effective line management, and the company employs approximately 75 industrial engineers who work on queue management issues for its worldwide parks. Interactive screens entertain patrons in many lines, and signs inform those in line about the estimated length of their wait. Constantly monitoring wait times, the parks will also direct popular characters (such as Goofy or Captain Jack

Sparrow) to make the waiting experience more eventful for customers. And Disney has recently added video games to many rides' waiting line areas.

The goal of queue management is to improve the customer experience while minimizing costs and maximizing profits. The bottom line is making customers comfortable. To accomplish this, an establishment should do everything possible to avoid waiting line congestion.

Wait time – not prices, not selection, not product quality – is the number one factor impacting customer satisfaction. And when it comes to wait time, perception is more important than reality. Studies have shown that customers perceive wait times to be nearly 25% longer than they actually are. A recent study revealed that a wait that exceeds six minutes can often be a breaking point for a customer. Many customers abandon their attempt to purchase at that point.

What happens when a patron encounters long lines (or what they perceive to be a long wait time)? The reactions can include:

Balking: Deciding against even entering the queue, and leaving the store

Reneging: Entering the line, but then becoming impatient and eventually leaving the line and store

Jockeying: In cases where there are multiple lines (such as supermarkets or some big-box stores), customers will shift from one line to another.

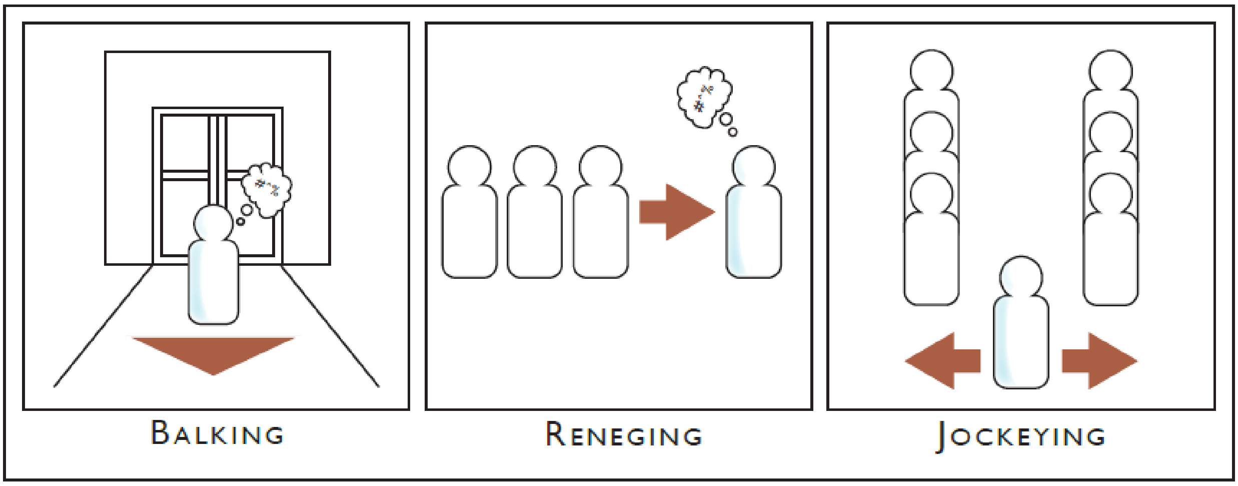

Fig. 1.2. Balking, Reneging, Jockeying

Customer Flow Management (CFM) Determining the optimum queue management plan for any given location is often part of a larger assessment of customer behavior and satisfaction. Customer Flow Management (CFM) is a process which takes into account the entire customer experience, from the time they arrive at your site to the completion of their "transaction" to post-service analysis. Any business which has face-to-face dealings with customers – including retail stores, restaurants, banks and financial service providers, social or government service offices, hospitals and other medical facilities – can increase their level of customer service satisfaction and boost their bottom line by implementing basic CFM practices. Customer Flow Management plans have proven to be increase sales (both in terms of immediate impulse buys and future customer loyalty) by producing happier customers. It increases your staff productivity (thus decreasing your costs) by efficiently matching staff members to customers. And it gives you management data about your customers and your processes, which can lead to ongoing competitive advantages.

The first step to implementing Customer Flow Management is to assess your current situation. Gather data on:

- the number of customers at your site per hour or per day
- your peak customer times
- the average customer wait time
- the number of "open" service points you have at any given time
- the average amount of time it takes to service a customer
- all feedback (both positive and negative) from customers
- any identifiable patterns regarding your staff's productivity.

Visualize the improvements you want to make and establish your key performance indicators (KPIs) to measure how CFM can align with your targeted goals. Is your top priority to increase sales? To increase customer satisfaction levels? To maximize staff efficiency? Identifying KPIs can help you prioritize which Customer Flow Management techniques you will initially use.

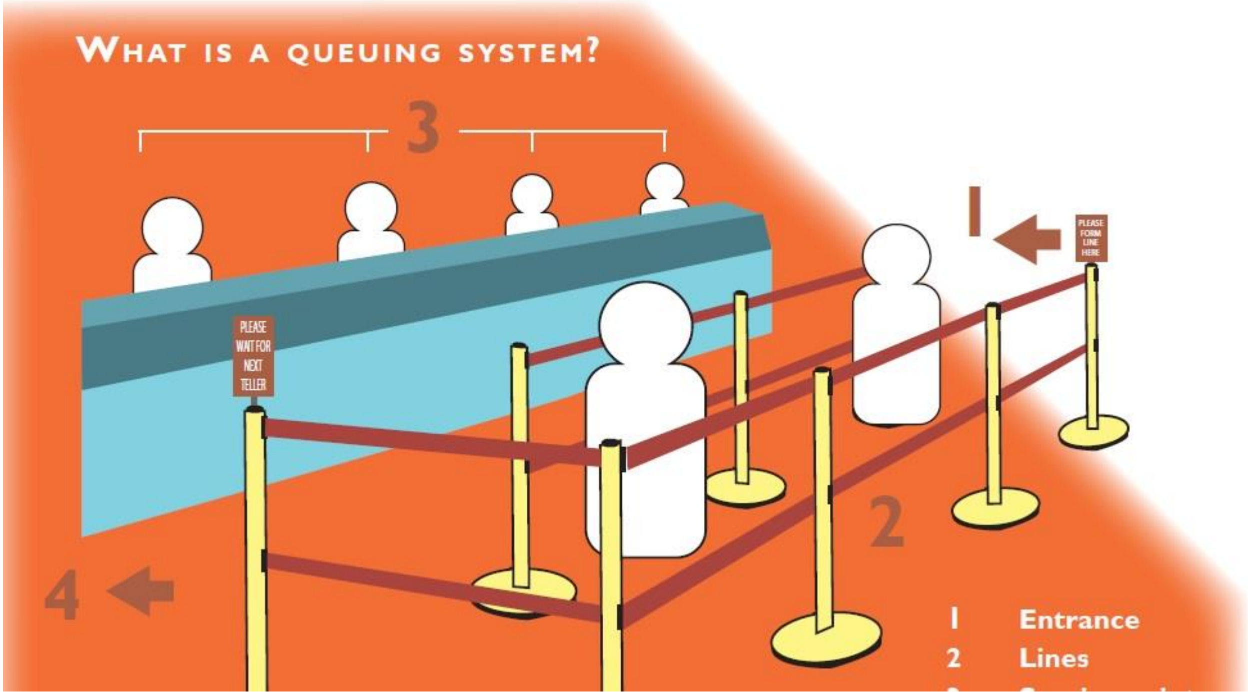

Fig. 1.3 Queue system

A thorough analysis of your current situation may lead you to conclude that one or more of the following actions will improve your customer flow management:

• You may need to redesign your physical space and move fixtures so that a line management system works logistically given your customer numbers and available space

• You'll probably need to acquire line management products (or enhance your current supply). The nature of these products will depend on whether you plan to roll out a linear queuing system or a virtual queuing system (both explained below)

• A linear queuing system will employ line management products, such as a portable post and retractable belt system, or a traditional post and rope system. Other related products include signage, merchandising fixtures (to enable customers to make point of purchase sales while they are in line) and possibly audio or video alert systems (to inform patrons of when the next available staff member is ready to serve).

• A virtual queuing system will likely require components such as kiosks, video display units, and accompanying software.

• Set up a system to analyze the data after the roll out of your Customer Flow Management process. Compare the results to your previous process. Build in time and materials for staff training to respond to the plusses and minuses of what your data tells you.

Different Queuing Systems

How do you know whether your location will benefit most from a linear queuing system or a virtual queuing system? Different environments require different queuing systems.

Linear Queuing Linear queuing is most frequently used in retail applications. Linear queuing is perceived as fair, and wait time is minimized, as one patron is ready to be served as soon as another is finished. The most common type of linear waiting line is one in which there is a single line and a single cashier or service counter. This is usually the situation in small stores and some fast food restaurants. Usually, only minimal line management products are needed in these settings – perhaps a few stanchions (with accompanying retractable belts or ropes) are necessary to visually denote the line space. For busier locations, a more elaborate queuing system is the "Single Queue – Multiple Service Points" arrangement. This "first come, first serve" set up is frequently seen at airports and banks. Customers line up in the order in which they arrive, and they are called to the service desk by the next available agent.

Single Line Queuing Systems By managing your customer waiting lines more efficiently, you can increase your bottom line. Installing a single line queuing system can speed up customer flow by 30% and reduce "walk-aways" by up to 96%. Based on the "first come, first served" theory, single line queuing systems ensure that customers are served by the first available check-out station. Central Display Units (CDUs) provide information for customers in the line, while Positional Display Units (PDUs) provide information at each cashier point. Customers are called to each position by the press of a calling button by the cashier, meaning that customers are informed of when an agent is open immediately. Single-line queuing systems can also feature visual and audio messages that communicate promotional messages, enabling you to effectively market to your customers while they are in line.

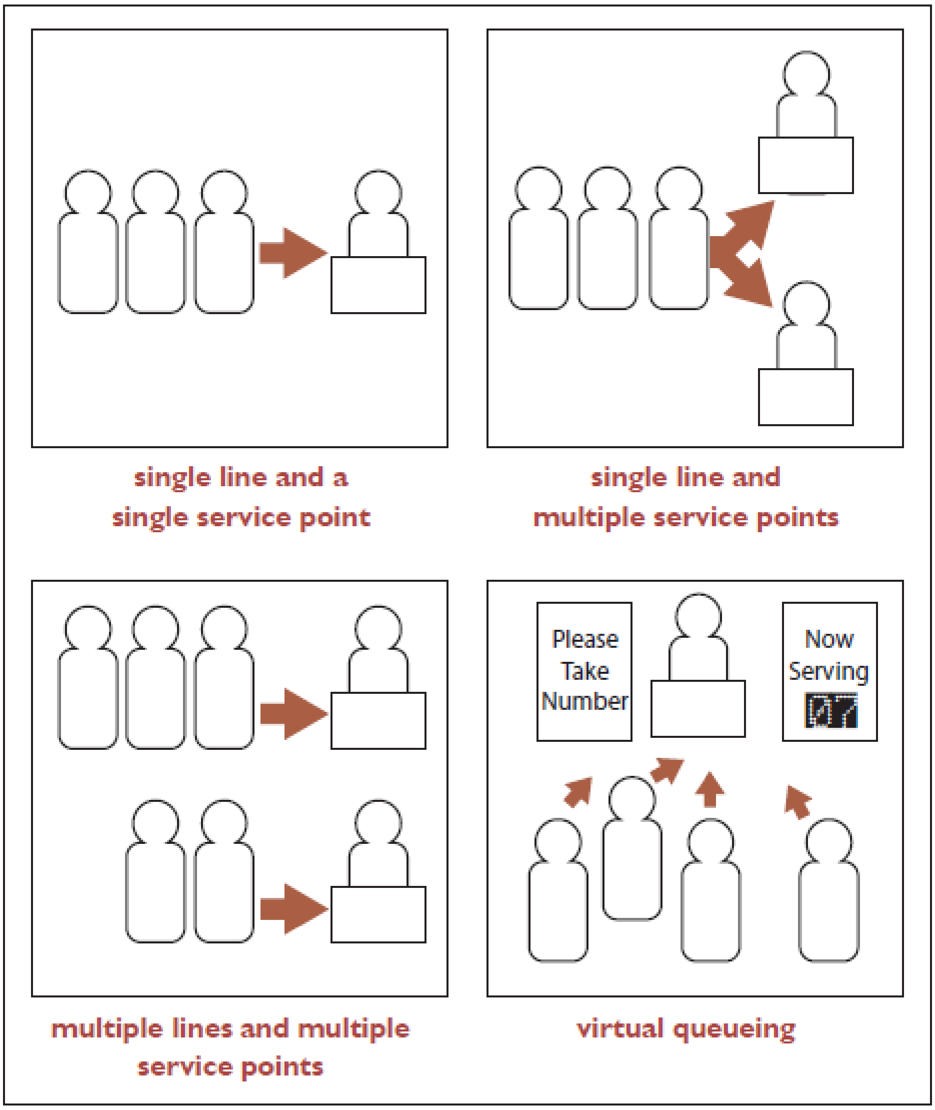

Fig. 1.4. Different Queuing Systems

Don't Make Customers Choose a Line

The linear queuing option which has the most potential negative ramifications is the "Multiple Queue – Multiple Service Points" option, which, with the exception of supermarkets and some fast food restaurants, is not favored by most locations. The danger in this case is that customers are forced to choose a line and through no fault of their own, may be stuck in a slow moving line, which they will perceive as a very frustrating experience.

Virtual Queuing

With virtual queuing, there is no physical line of customers. Instead, customers either check in, or are otherwise identified upon arrival. They then generally receive a ticket and will be called to meet with a service provider at an appropriate time. But they are free to move about a waiting room and do not have to stand and remain focused on how a “line” in front of them is moving. They can fill out forms, read, or carry out personal conversations on their phone. Or, you can direct video or audio messages to them designed to capture their attention while they are waiting. Virtual queuing is most ideal for hospitals and the offices of other health care providers, as well as financial service providers. If the company wants to identify customers before they reach a staff member (thus enabling prep time), virtual queuing is the solution for company.

Queue Management Products and Their Benefits

Portable Post and Retractable Belt Line Management Systems Portable posts with retractable belts are a popular line management system at banks, cafeterias, airports, concession stands, and trade shows. This retractable belt system features a belt, cassette unit, and posts. The system is designed to identify a site’s line space, organize lines of patrons, and keep those lines moving efficiently. Posts can be set up and configured in a different lengths and positions, depending upon the needs of the situation. Position stanchions to make most effective use of floor space. Often placing stanchions at exact right angles takes up more space than necessary because people round corners in an arc. Consider where angled lines of stanchions might be better than strict horizontal or vertical arrangements.

Fig. 1.5. Queue belt

Choosing Retractable Belt Barriers : A Primer

Here are some factors to keep in mind when assessing the strengths and merits of various retractable belt stanchion options. Making the right choice could save you money (by minimizing the number of barriers you need) and ensure the safety of your site and patrons.

Post Quality and Size

A quality post will feature single-tube construction to prevent unsightly seams in the middle of the post. Posts made of steel will ensure years of use, even in heavy-duty environments. Because your floor space is valuable, you don’t want bulky posts taking up too much space. Many brands of high-quality stanchions are only two inches in diameter, and you can also choose strong bases that don’t use excessive floor space.

Balance the post’s strength and durability with its weight – the lighter the post, the easier and quicker it will be to move it into the place you need it. Since you want posts to attractively blend into your environment, look for models that offer you a choice of finishes, such as chrome, stainless steel, and brass.

Belt Options

For longest life-span, belts made of woven polyester will retain an attractive "new" look for a longer period of time. Standard belt widths are two-inches or six-inches (top-to-bottom). Standard belt lengths (left-to-right) are 7.5 feet and 13 feet, although other lengths are available. Remember that the longer the belt, the fewer the number of necessary posts will be.

Some retractable belt barriers are available with two horizontal belts. This feature provides extra security and helps keep children in line. And some suppliers of retractable belt stanchions also offer the option of having belts printed with messages or advertisements.

Belt Safety

Make sure that any retractable system is safe – you do not want any belt that retracts with an amount of force that could cause injury to anyone in its path. A high-quality retractable belt system will feature a belt that will, upon release from a post, fall to the floor and then slowly and safely retract back into the post. Ask about each model's cassette unit – it should feature an anti-tamper belt locking system to prevent accidental release of the belt. High quality retractable belt posts will have a retraction mechanism that will last for more than 250,000 cycles.

Variations

There are some additional retractable belt barrier options for settings that have different needs than typical indoor line-management applications. Wall-mounted barriers are used in situations where a permanent but retractable barrier is needed without taking up any floor space. Wall-mounted barriers can close off space between two walls, or between one wall and a post. Outdoor posts, made of UPVC to withstand heavy weather conditions, are used when a line management system is needed outside, or to convey a strong visual impression about a no-access area. They feature bases that can be filled with liquid, sand or other substances in order to provide extra weight and stability.

Other Queue Management Product Options

Traditional Post and Rope

Traditional post and rope provides guidance and line management at quieter, often upscale and indoor sites, such as banks, hotels, museums, movie theatres, and trade shows. Attractive steel or brass posts and velour posts, with numerous post top and base style options, can match any stylish décor. Post rings can accept rope from any direction, and post tops accommodate signage to provide information to patrons in line.

In Line Merchandising

What may seem upon first glance to be a crassly commercial tool, in-line product merchandising stands within lines, has also proven to be very well-received by patrons.

Displays of point-of-purchase products are not just a sales tool; they are a queue management tool. For those interested in the featured products, this in-line (or in-queue) merchandising is convenient. But even those not inclined to buy those particular products view these displays as a way to help relieve the boredom of standing in the line. Being able to look at other products reduces perceived wait time.

Signage

Clear and accurate signage is another key to effective line management. Signs can be attached to the top of portable posts. Signs regarding line and check-out entrances, exits, and policies should be clearly visible to patrons.

To direct attention to point-of-purchase products, headers featuring promotional messages can be placed on top of merchandising panels.

In-Line Merchandising Boosts Retail Sales, Customer Satisfaction

What are the characteristics of customers who are in waiting in line at your site?

First, in one respect, they all feel as if they are “done” shopping. Secondly, they are no longer dispersed among the various aisles or departments of your store – they are now grouped together. They are now sharing the exact same experience – waiting to check out.

No other location in your store has as big an impact on customer satisfaction as this pre-checkout queue. And while customers are looking forward to exiting your store, they are also a captive audience. They are very receptive to impulse purchases.

There are a number of ways to make sure the line experience is a positive one for your customers. Most importantly, make sure your line management system is as efficient as possible.

And when the customers are confident that the line will move efficiently, they have positive feelings. They are open to messages from you. Thus, this line is the perfect place for your advertising messages, and for a display of point-of-purchase products.

A sophisticated in-line merchandising system not only provides a defined physical layout for your check-out line, but also features structures upon which products can be displayed – shelves, baskets, hooks and bowls. Attractive products will be in the sight-lines of your customers, and within easy physical reach.

You can maximize your store's dollars-per-square-foot ratio and increase impulse purchases by up to 30% with in-queue merchandising posts, panels and displays. Proven to work at hardware stores, sporting goods stores, department stores, pharmacies, and electronics stores, these systems are a win-win for both the customers and the store.

1.4. Queue Management and How It Improves Airport Operations

Airports are notorious for their queues and in order to avoid the extended wait times, people often leave their home hours in advance of their flights. Many others have stopped flying through specific airports just because of the never-ending congestion. Recently, however, some airports have started employing queue management technology to reduce wait times, optimize passenger experience, and increase their revenues.

Airport waiting time is stressful and can cause headache when you had 10-12 hours long flight and still have to stand in queues for another 1-2 hours. You have to stand in line for luggage checking, show travel document, immigration, go through scanning device and then to your terminal. I always have to experience this queue because I have to change 3 flights; Ahmadabad to Mumbai, Mumbai to Madrid, Madrid to Valencia. If you have connected flight from different airport then again you have to stand in line for all this things again. The journey seems exhausted.

There is barcode system to estimate the rush of people at the choke point so that additional staff can be arranged and new queuing channels can be set. Though, this system does not give real time solution for the queues

The new BLIP systems can track the mobile phones and other devices and enable airports to track the movements of a traveler. It is installed Norwegian airports, Birmingham airport, Manchester airport, etc. BLIP system was founded in 2003, is a business intelligence company based near Aalborg, Denmark. In 2010, the queue prediction module was developed to provide airports and their passengers with accurate wait time information.

How BLIP works:

“Airports can use this information to understand things such as which parking spaces, airport entrances and services passengers use, how many people show up at airport processes, when they arrive and how long they wait,” says Christian Bugislaus Carstens, BLIP’s marketing manager. But what if personal data of the traveler reveled and misused. There is a question of security and protection of personal data. But “each mobile device has a unique MAC address which is assigned to the device during manufacturing and cannot be modified. MAC addresses do not link to any individual user data, thus personal information is not revealed, and no personal data is collected, disclosed or otherwise processed by BLIP Systems, in compliance with the EU directive about privacy” says Carstens.

In a sector as competitive as the travel industry, you do not want to be left behind when tools like these are being utilized. Here are ways that queue management solutions can be used to improve airport efficiency:

1. Monitor passenger traffic

There are few businesses busier than airports, and they cater to a large number of passengers at every hour of the day. People counting and queue management technology can help airport personnel figure out exactly how many people pass through their halls per day, how many people are on queues around the airport, and the average time that every passenger spends on the queue.

This information will be useful in implementing measures to manage crowds more efficiently. The airport could employ more staff, open up new lines, or improve service delivery to ensure that people are moved out of queues more efficiently. Real-time passenger tracking can also be used to identify areas that are congested, and steps can be taken to resolve the issues that are causing the hold-ups.

2. Determine peak periods and seasons

Airport managers can easily figure out which hours will be their peak periods of the day by checking their logs for when larger flights are arriving and departing. They can also assume, to a certain degree of accuracy, that the summer and holiday periods will be busier than the winter months. However, these analytical methods are rudimentary and they won’t tell you exactly how much more passengers to expect. They can’t tell you just how much more staff you need to deploy or what patterns appear consistently from season to season.

Intelligent queue management tools will provide you with historical records and help you anticipate the number of passengers to expect during peak periods and seasons. These figures can be used to deploy staff and manage queues better. Additionally, these tools can tell you to a 98% accuracy which periods are your slowest and which are your busiest.

3. Measure and optimize employee performance

To ensure that the passengers that pass through the airport have an enjoyable experience, you want to reduce the time they spend at check-ins and security booths to the barest minimum. With queue analysis tools, airports can find out how much time customers spend in front of an employee and which employee responds the slowest.

The ideal solution would be to come up with a benchmark, the number of minutes it should take on average to respond to a passenger. This can be used to train airport employees on how to keep things short and effective.

4. Increase shopping times

Many passengers look forward to visiting the duty-free shops whenever they are at the airport. However, when the queues are too long, they are left with too little time and they miss out on the buying experience. By reducing the time passengers spend in queues, airport mangers can increase their shopping time, thereby maximizing every passenger's airport experience. Additionally, the more time that passengers spend at various airport kiosks, the more the revenue for airport retailers, and the better for the airport.

As a matter of fact, airport retailers may also take advantage of queue management technology to reduce customer wait times at their stalls.

5. Maximize airport real estate

With real-time customer tracking, airports can note the paths that passengers spend the most time on and the shops they love to visit. This information will be used to set rent prices for the shops and monetize passenger footfalls. When trying to attract new retail partners, you may show them the statistics of how many visitors pass through the airport; these are all potential customers.

Furthermore, if there are areas in the airport that passengers linger that have no shops, you can also present the traffic data to prospective retailers and rent the space out to them at an even higher rate, further increasing airport revenue.

This is one of those instances where a piece of technology has a maximum upside and no downside. As an airport manager, queue management tools not only help you reduce queues and congestion, they also help you optimize your operations. In addition to guaranteeing all visitors a good experience at your airport, you also have the chance increase revenues. Maximum upside!

2. ANALYTICAL PART

Air Transportation Management Department				NAU 20. 09. 46. 200EN				
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St. Inspector	Yulia V.Shevchenk				FTML 275ОП-.202Ма			
Head of the Dep.	Yun G.							

2.1. General information of Casablanca Mohamed V International Airport

The Casablanca Mohamed V International Airport (IATA: CMN, ICAO: GMMN) (French: Aéroport international Mohammed V / Arabic: مطار محمد الخامس الدولي / transliterated: Matar Muhammad al-Khamis ad-Dowaly) is an airport operated by ONDA (National Airports Office). The airport is located approximately 30 kilometers outside of the city of Casablanca in Morocco in the Nouaceur a suburb 30 km south-east of Casablanca, Morocco. The airport is around a 40-minute drive from Casablanca city centre. This airport in Morocco is the hub for Royal Air Maroc, Air Arabia Maroc, Jet4you and Regional Air Lines. The Casablanca Mohamed V Airport in Morocco has an average of 6 million passengers pass though the terminals in a year . Mohammed V International Airport, also known as Casablanca Airport, is the main international airport serving Casablanca, Morocco. The airport mainly facilitates flights around Africa and Europe, as well as some flights to destinations in North America, South America and parts of Asia.

Casablanca Mohammed V International Airport is a hub for Royal Air Maroc, Royal Air Maroc Express and Air Arabia Maroc. It's the busiest airport in Morocco and one of the busiest airports in the continent of Africa.

The IATA airport code for Mohammed V International Airport is CMN.

About the name: Casablanca Airport is named after the late Sultan Mohammed V of Morocco.

Casablanca Airport is the largest airport in Morocco and counts with a network of approximately 100 destinations served by more than 30 airlines, being Africa the continent with more connections.

It is the main hub for the national carrier Royal Air Maroc, Jetairfly, Air Arabia Maroc and RAM Express. The passenger traffic in the airport has been growing the last decade except in 2012. In 2017, 9.35 million passengers travelled to and from the Airport, and is expected to exceed this figure during next years. In Africa, Casablanca airport is between the five busiest airports in the continent.

Runways

The Mohamed V Airport has two asphalt runways that are both 3 720 meters in length and are both used for take offs and landings. There are many airlines that operate flights in and out of the Mohamed V Airport, including airlines such as Kuwait Airlines, Tunisair, Qatar Airlines, Fedex, Royal Jordanian, Syrian Arab Airlines, Air France, Emirates Airlines, Royal Air Maroc, KLM Royal Dutch Airlines, British Airways, DHL Air, Air Malta, Lufthansa, Regional Airlines, UPS and Egyptair. Casablanca Mohammed V International Airport has two runways that are the same in size and used equally for operations. Both runway 17L/35R and runway 17R/35L are 3,720 m in length and can handle aircraft as big as the Boeing 747.

Terminals

There are three terminals at Casablanca Mohammed V International Airport. However, only two of the three existing terminals are currently in use.

Terminal 1

Terminal 1 is the first active terminal at the airport. It facilitates a mix of international and domestic flights and has a train station on its basement level.

Terminal 1 went recently under refurbishment works, which increased its capacity to handle more passengers annually, the number estimated is 20 millions per year.

Terminal 1 hosts both arrivals and departures of international and domestic flights.

LEVELS

- Basement level: Train station.

- Ground level

- First level: It has a total of 28 boarding gates, more than 40 check-in counters and it has an integrated shopping mall.

Services

Available services at Casablanca Airport Terminal 1:

- ATMs
- Banking services
- Post office
- Business centre
- Local food and pizzeria

Lounges

Pear Lounge: Location: Terminal 1, first level. Services: Air conditioning, beverages, children's play area, conference rooms, game's room, disabled access, newspapers, magazines, TV, Wi-Fi, work stations. Service hours: 24 hours.

Terminal 2

Convives de Marque Arrivals Lounge (Pearl Lounge): Terminal 2, Landside (Level 1). Available services: Beverages, air conditioning, children's play room, disabled access, newspapers, magazines, TV, Wi-Fi. Opening hours: 24 hours. Entrance fee: US$ 50 / person.

Convives de Marque Departures Lounge (Pearl Lounge): Terminal 2, Airside (Level 0). Available services: Air conditioning, beverages, children's play room, disabled access, newspapers, magazines, TV, Wi-Fi. Opening hours: 24 hours.

Terminal 2 opened in 2007 and is the second active terminal at the airport. Terminal 2 facilitates international flights exclusively. The terminal is mainly used for flights operated by Royal Air Maroc. Terminal 2 is the main terminal serving international flights.

Casablanca airport terminal 2 levels

- Ground level
- First level

Services

See the available services at Casablanca Airport Terminals:

- ATMs
- Banking services
- Food and drink concessions

- Duty-free and shopping mall area

Terminal 3

Terminal 3 is inactive and not currently in use.

Facilities

The airport in Casablanca has many facilities available to passengers that include banking facilities, a foreign exchange service, ATMs, public telephones and clean and hygienic restrooms. Duty free shops, gift shops, newsstands, cafés and restaurants are available. For passenger convenience, the airport has a postage service and a business center. The business center allows passengers to make photocopies, send important faxes or log onto the internet to check on their e-mails. There is also a prayer room, pharmacy, medical center and first aid facilities that include an ambulance service. The airport in Casablanca has specially adapted restroom facilities and lifts to accommodate disabled passengers.

Transport

Transport from the Casablanca Mohamed V Airport to the city center of Casablanca, is available through taxi services, shuttle services, buses and railway. Car rental companies such as EuropCar Hire, Hertz Car Rentals, Budget Rent-a-Car and Avis Car Hire are located in the airport building. The airport has 1 600 parking bays in its long term parking area, and approximately 880 parking bays in the short term parking area, that is located outside of the Arrivals hall.

Casablanca Mohammed v international airport (CMN) - ground transportation

Casablanca Airport has several options for those passengers who wish to transfer to and from downtown Casablanca. The following means of transportation are available at Casablanca Airport:

How to get to / from Casablanca Mohammed V airport

If you want get from the Casablanca Mohammed V International Airport to the city center or to other cities or resorts, or vice versa, without any problems with local transport, you can use the transfer order the search form below. This way to get from the airport is different from the ordinary taxis, because it's more comfortable and you will not have problems with the language barrier (you do not have to explain to the driver in an unknown language where you need to get). When you will make a booking, you can specify special travel conditions, if they are required, such as a trip with children or people with disabilities. When traveling with children, special child chairs provided, if the law of the country is required.

When you will arrive at airport, the driver will wait for you after boarding the plane with a sign with your name, and you can easily get to the desired place from any airport in the world.

By driving

Casablanca Mohammed V Airport has car rental and parking facilities.

he airport can be reached by the A7 Casa-Berchid motorway via Bouskoura. Driver should follow the signs to Marrakesh and Casablanca airport.

From Rabat, use the A3 and A5 and following the signs to Marrakesh and Casablanca airport.

From Marrakesh, use the highway to Casablanca-Rabat and exit at Casablanca airport.

By train

You can use ONCF trains to travel to/from the airport from the city centre (stops Casa Port station and Casa Voyageurs station), as well as from other Moroccan cities. From the underground train station at Casablanca Airport (Aeroport Med V) you may transfer to either Mers Sultan, Casa Port, Casa Voyageurs or L'Oasis.

The train takes roughly 45 minutes from the city centre and is the most economical way of travelling to/from the airport. Opening hours: From 06:00 am to 10:00 pm. Total trip time just take 45 minutes.

The train station is located at Terminal 1 of the airport.

Trains depart from Casablanca Airport to downtown or vice versa every hour between 06:00 am and 10:00 pm approximately, 7 days a week.

Journey time is about 45 minutes.

Stops Access to Casablanca Airport is assured by train via Mers Sultan, Casa Port, Casa Voyageurs and L'Oasis stations.

If you wish to get to the city centre, the best stop to take off it without a doubt Casa Port Station. On the other hand, Casa Voyageurs is a little bit far from downtown.

In case you wish to connect to other Moroccan cities (Meknes, Marrakech, Tangier, Oujda, etc), your best option is to get to Casa Voyageurs.

Please, make sure that the scheduled hours match with the times to your final destination, since they might change. Note that ONCF trains, including the ones to and from Casablanca Airport, tend to delay. Make sure you have enough time to avoid hassles.

The train station is located at level -1 in the arrivals area of Terminal 1. The station is called Aeroport Med V.

The single second class ticket cost is around MAD 42.00 (around USD 3.00).

For a first-class single ticket, it usually costs +50%.

You can purchase your ticket at Casablanca Airport train station at both booths and ticket machines.

By bus

Bus information

Route The bus line operated by CTM follows this route: Casablanca Airport – Californie suburb – Boulevard Abdelmoumen – Boulevard Hassan II – Place de Bandoeng – CTM bus terminal (located behind Sheraton Hotel).

Location

CTM bus line just stops outside Terminal 1.

Fares One-way ticket fare is around MAD 20.00.

You may purchase your ticket on board to the driver.

Bus company CTM operates services to Casablanca Mohammed V Airport from the city center.

Estimated journey time is of 45 minutes.

CTM buses serve Casablanca Airport every hour.

Royal Air Maroc and Air Arabia offers bus transfers to neighboring cities.

By taxi

You can get a taxi from one of the designated taxi stands or flag one down in the street. Although, when flagging a taxi down, be careful of potential scammers.

Alternatively, get the person(s) in charge of your accommodation to order a taxi for you.

You can also use taxi apps such as Careem to order a taxi conveniently and cheaply.

Get within 45 minutes to downtown Casablanca from the airport. Find the taxi at the ground level, outside the arrivals hall. One-way trip to downtown is about MAD 250.00 - 300.00.

Taxi is without a doubt a convenient mean of transportation, since Casablanca Airport is located 30 kilometres south-east of Casablanca, that means an average transfer time of 45 minutes.

Casablanca official taxis are painted in white colour. There are a couple of types of taxis in Morocco: Grand and petit.

Grand stands for Mercedes Benz diesel sedans, which depart to downtown when they are full of passengers and stop at the meeting spot for taxis, like a bus. These taxis follow the route between different cities in Morocco. It is not recommended to take one in case of carrying large baggage or simply getting to downtown from the airport.

On the other hand, petit taxis are the typical four passengers cab which just follows the route between the airport and downtown.

We recommend to avoid boarding a taxi with the taximeter either broken or turned off, since you could be a victim of a scam. In that situation, you'll have to negotiate the fare with the driver, which is not recommended to do so.

In case of boarding a grand taxi, there will be usually a person in the group negotiating fares and communicating with the driver on behalf of the tourists. You should do the negotiation with that person.

Aside, avoid taking a non-authorized taxi. Remember official taxis are painted in white colour.

A typical tactic to rip off tourists is to approach to them, waving or whatever to get their attention and persuade them to take a ride. Don’t board their taxi since you’d be victim of a scam.

Taxis are located at level 0, outside the arrivals area, and are available 24/7.

The following taxi companies operate at Casablanca Airport:

- Casablanca Airport Taxis
- Casablanca Airport Cab Morocco

It is polite to tip the driver (with rounding-up the final fare will be enough). Although in the cities is not necessary to do so, in case of travelling between cities, it is what is usually done.

Official and authorized prices at Casablanca Airport are shown in a panel located at Terminal 1 and they are agreed by the local council.

Fares to other popular locations:

Rabat / El Jadida: MAD 650.00 (USD 73.00) - Travelling time: 1.5 hours.

Marrakech: MAD 1.000 – 1.500 (USD 112.00) – Travelling time: 2-3 hours.

Beni Mellal: MAD 900.00 (USD 101.00) – Travelling time: 2.5 hours.

Fez: MAD 1.300 (USD 147.00) – Travelling time: 3.00 hours.

Tangier / Tetouan / Essaouira: MAD 1.500 (USD 170.00) – Travelling time: 3-4 hours.

Shared rides

Shared ride service is available to those who wish to share a ride and pay a flat rate to certain destinations if multiple parties are available for the trip. Apps such as Uber may be useful to do so.

Car rental

Casablanca Airport offers to their passengers car rental options at both terminals. Many agencies provide car rental services from Casablanca Airport. Use the search engine in this page to compare all the car rental companies and options that you have and book online your car before your arrival at Casablanca!

- Afrique Rent - +212 05.22.53.85.51

- Avis - +212 05.22.53.90.72

- Budget - +212 05.22.53.91.57
- Ennasr Car - +212 05.22.53.82.66
- Europe Car - +212 05.22.53.91.61
- Express - +212 05.22.53.94.13
- First Car - +212 05.22.53.91.77
- Hertz - +212 05.22.53.91.81
- Jet Car - +212 05.22.53.83.67
- National Alamo Car - +212 05.22.53.97.16
- Nava Tour - +212 05.22.53.99.40
- Renaissance Car - +212 05.22.53.95.34
- Sixt - +212 05.22.53.80.99
- Thrifty Car - +212 05.22.53.20.01
- Liege Tour - +212 05.22.53.97.07
- Majestic Limousine - +212 05.22.53.90.90
- Select Rent - +212 05.22.53.81.28
- Air Car - +212 05.22.53.93.84
- Genial Car - +212 05.22.53.94.93
- Dollar Car - +212 05.22.53.97.94

Although there are some car rental offices in Casablanca city, the best place to rent a car in Casablanca is definitely the airport.

Road

Mohammed V Airport can be reached via A7 Casa-Berchid motorway via Bouskoura / follow the signs to highway Marrakesh and take the Airport exit.

From Rabat use A3 then A5, or also follow the signs to highway Marrakesh and take the Airport exit.

From Marrakesh, follow the highway to Casablanca-Rabat and take the Airport exit.

Parking Casablanca Mohammed V *international airport*

There are both long and short term parking spaces located at Casablanca Airport.

They are located just in front of both terminals 1 and 2 with more than 1,050 parking places each one.

Fares

- 1h - 6 Dh.
- 2h - 9 Dh.
- 3h - 12 Dh.
- 4h - 14 Dh.
- 5h - 17 Dh.
- From 5 to 12h: 22 Dh.
- From 12 to 24h: 35 Dh.

General information about Casablanca Mohammed V International Airport

Airport name: (Casablanca Mohammed V International Airport)

Largest and busiest airport in Morocco

Airport opening year: 1943

Local time GMT (winter/summer): 0/+1

Geographic coordinates: Latitude (33.37), Longitude (-7.59)

Location: 30 km (16 miles) southeast of the city of Casablanca

Number of terminals: 2

IATA code: CMN

ICAO code: GMMN

Postal address: B.P. 8101, Casablanca-Oasis, Morocco

Office phone number: +212 2 339 040

Flight information: +212 2 339 040

Fax: +212 2 339 901

Country: Morocco

Country code: MA

Certification :

ISO 9001v2008 (February 2009))

ISO 14001v2004 (February 2013))

ISO 9001v2008 (Nov. 2009)

Terminal facilities:

Area T1 : 76 000 m2

Area T2 : 66 000 m2

Area Q3 : 4, 000m2

Current capacity: 14 MPAX per year

Aircraft park :

Area : 250 000 m2

Capacity: 64 aircraft including 11 large aircraft

Bridges: 19 including a triple bridge for the reception of aircraft of type A380

Track :

2 parallel tracks

Orientation: 17/35

Length: 3 720 m

Width: 45 m

The airport accommodates all types of aircraft

Equipment:

Precision approach: CAT III-A

SLIA Category: 9

Surveillance equipment: Mssr monopulse RADAR

Weather Equipment: Automatic Station

Radio Navigation Aid : 2 VOR / 2 DME / 3 THEY / 1 NOTE / 1 LOC

High intensity markup: axial and lateral

Telecommunications and meteorological equipment required for flight coverage

Facilities

Casablanca Mohammed V International Airport has an array of facilities, services and airport lounges to enjoy while waiting at the airport.

Facilities Include:

WIFI

ATMs and banking

Currency exchange

Passengers services

Shopping

Dining

Medical facilities

Prayer room

Smoking area

Lounges

Royal Air Maroc Lounge

Located at Terminal 1.

Free snacks

WIFI

Newspapers and magazines

TV screens

Flight monitors

Exclusive to Royal Air Maroc Business Class and First Class passengers

Pearl Lounge

Located at Terminal 1.

Free snacks

Free bar

WIFI

Flight monitors

Newspapers and magazines

TV screens

Children's area

Smoking area

Conference rooms (extra cost)

Pearl Lounge

Located at arrivals at Terminal 2.

Free snacks

WIFI

Showers

Flight monitors

TV screens

Newspapers and magazines

Smoking area

Pearl Lounge

Located at departures at Terminal 2.

Free premium food

Free bar

WIFI

Newspapers and magazines

Flight monitors

TV screens

Smoking area

Royal Air Maroc The Casablanca Lounge

Located at Terminal 2.

Free premium food

Free bar

WIFI

Flight monitors

Newspapers and magazines

TV screens

Smoking area

Airlines that fly to Casablanca Mohammed V international airport.

Based at Casablanca Mohammed V Airport

- Royal Air Maroc,
- Royal Air Maroc Express
- and Air Arabia Maroc are.

Table 2.1

Full list of airlines that fly to/from the airport

AIRLINE	COUNTRY FROM
Aegean Airlines	Greece
Air Algérie	Algeria
Air Arabia Maroc	Morocco
Air Canada	Canada
Air Europa	Spain
Air France	France
Air Malta	Malta
Alitalia	Italy
American Airlines	USA
Binter Canarias	Spain
Corendon Airlines	Turkey
EgyptAir	Egypt
Emirates	UAE
Etihad Airways	UAE
Eurowings	Germany
Gulf Air	Bahrain
Iberia	Spain
Lufthansa	Germany
Mauritania Airlines	Mauritania
Oman Air	Oman
Pegasus Airlines	Turkey
Qatar Airways	Qatar
Royal Air Maroc	Morocco
Royal Air Maroc Express	Morocco
Saudia	Saudi Arabia
TAP Air Portugal	Portugal

Transavia	Netherlands
Transavia France	France
TUI Fly Belgium	Belgium
Tunisair	Tunisia
Turkish Airlines	Turkey
Vueling	Barcelona

Airport hotels

Casablanca Airport counts with an airport hotel, the Transit Hotel, located in Terminal 2, exclusively used by transit passengers.

On the other hand, the Atlas Hotel, counts with a conference room to host over 70 persons.

Airport lounges

The following lounges are available at Casablanca Airport:

Convives de Marque Arrivals Lounge (Pearl Lounge): Terminal 2, Landside (Level 1). Available services: Beverages, air conditioning, children’s play room, disabled access, newspapers, magazines, TV, Wi-Fi. Opening hours: 24 hours. Entrance fee: US$ 50 / person.

Convives de Marque Departures Lounge (Pearl Lounge): Terminal 2, Airside (Level 0). Available services: Air conditioning, beverages, children’s play room, disabled access, newspapers, magazines, TV, Wi-Fi. Opening hours: 24 hours.

Transfers

If you wish to transfer to and from Casablanca Airport on your own, there are several transfer companies available within the airport premises.

Cargo

As part of the development of the airport, and since Casablanca is one of the main trading and industrial cities in the southern Mediterranean, the cargo operations will expand in the next few years. A 30,000 sq metre cargo facility opened in 2008, with an annual processing capacity of 150,000 tonnes.

History of the airport

The Casablanca Mohammed V Airport was originally built as an airfield by the United States in early 1943 during World War II as an auxiliary airfield for Casablanca's Anfa Airport and was named Berrechid Airfield. The airfield handled various military transports as a stopover en-route to Port Lyautey Airfield or to Marrakech Airport on the North African Cairo-Dakar transport route. In addition, flights were flown across the Atlantic to the Azores on the Mid-Atlantic route which connected to Nova Scotia or East Coast United States airfields.

In addition to its transport mission, the airfield supported the North African Campaign with the Twelfth Air Force 68th Reconnaissance Group operating photo-recon versions of the P-38 Lightning and P-51 Mustang from the airfield. Elements of the 68th first arrived at Angads Airport in Oujda in November 1942 and moved to Berrechid in March 1943 upon its completion. It flew both antisubmarine missions over the Atlantic and photo-recon combat missions over German-held territory from the airfield until early September when it moved east to Massicault Airfield in Tunisia. With the end of the war in 1945, the airfield was turned over to the civil government.

During the Cold War of the early and middle 1950s, the airfield was reopened as Nouasseur Air Base and was used as a United States Air Force Strategic Air Command staging area for B-47 Stratojet bombers pointed at the Soviet Union. These operations later moved to Ben Guerir Air Base.

With the destabilisation of French government in Morocco, and Moroccan independence in 1956, the government of Mohammed V wanted the US Air Force to pull out of the SAC bases in Morocco, insisting on such action after American intervention in Lebanon in 1958. The United States agreed to leave as of December 1959, and was fully out of Morocco in 1963. SAC felt the Moroccan bases were much less critical with the long range of the B-52, and with the completion of the Spanish bases in 1959.

Even today, most locals still refer to the airport simply as "Nouasseur", this comes from the name of the suburb where it is located.

Incidents and accidents

On 24 August 1994 a Royal Air Maroc ATR-42 crashed near Tizounine while en-route from Agadir to Casablanca Mohammed V airport. The plane crashed with a steep dive in the Atlas mountains. All 40 passengers and 4 crew died in this accident. It is said that the captain disconnected the autopilot and let the plane crash deliberately. The Moroccan Pilots Union challenged these findings.

On 1 April 1970, a Royal Air Maroc Sud Aviation SE-210 Caravelle crashed on approach to Casablanca Mohammed V airport when it lost control at a height of about 500 feet. The fuselage broke in two. Sixty one of the 82 passengers and crew were killed.

Table 2.2

Summary

<table>
<tr><th colspan="2">Airport type</th><td colspan="2">Public</td></tr>
<tr><th colspan="2">Operator</th><td colspan="2">ONDA</td></tr>
<tr><th colspan="2">Serves</th><td colspan="2">Casablanca, Morocco</td></tr>
<tr><th colspan="2">Location</th><td colspan="2">Nouasseur</td></tr>
<tr><th colspan="2">Hub for</th><td colspan="2">• Air Arabia Maroc
• Jet4you
• Regional Air Lines
• Royal Air Maroc</td></tr>
<tr><th colspan="2">Elevation AMSL</th><td colspan="2">656 ft / 200 m</td></tr>
<tr><th colspan="2">Coordinates</th><td colspan="2">33°22′02″N 007°35′23″W / 33.36722°N 7.58972°W</td></tr>
<tr><th colspan="2">Website</th><td colspan="2">www.onda.ma</td></tr>
<tr><th colspan="4">Runways</th></tr>
<tr><th rowspan="2">Direction</th><th colspan="2">Length</th><th rowspan="2">Surface</th></tr>
<tr><th>m</th><th>ft</th></tr>
<tr><td>17L/35R</td><td>3,720</td><td>12,205</td><td>Asphalt</td></tr>
<tr><td>17R/35L</td><td>3,720</td><td>12,205</td><td>Asphalt</td></tr>
</table>

2.2. Analysis of Statistical Data of Casablanca Mohammed V airport

Table 2.3

Passenger traffic of Casablanca Mohammed V airport for 2010-2018 years period

Year	Passengers	Change, %
2010	7 243 462	-
2011	7 290 314	0,65
2012	7 186 331	-1,43
2013	7 559 751	5,2
2014	7 971 705	5,45
2015	8 180 083	2,61
2016	8 616 474	5,36
2017	9 357 427	8,6
2018	9 732 044	3,92

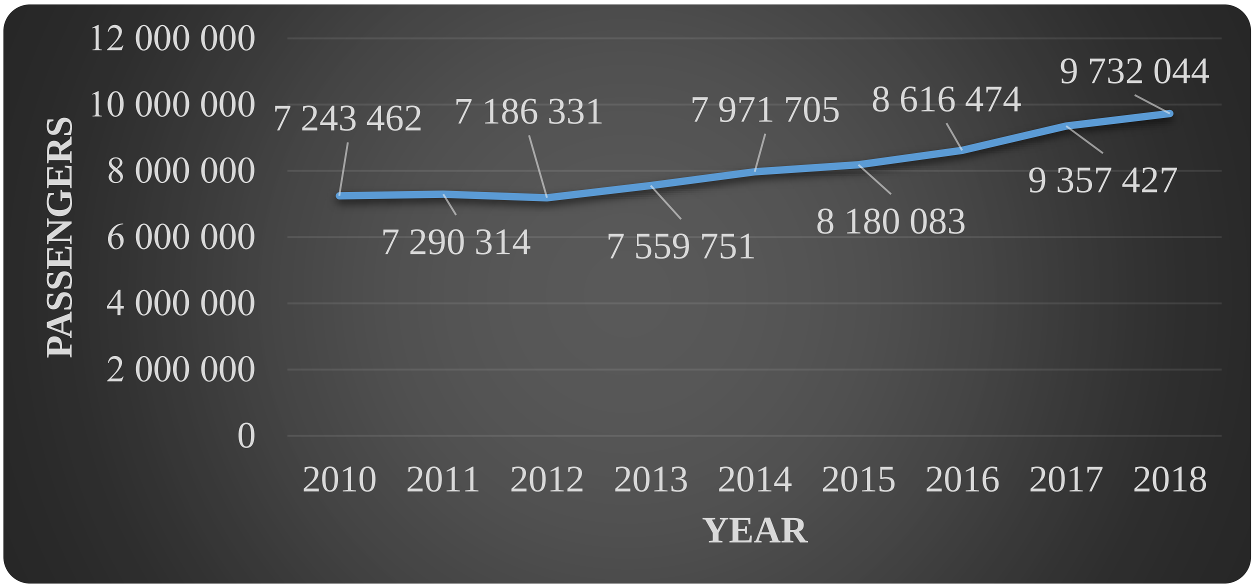

Fig. 2.1. Diagram of passenger traffic of Casablanca Mohammed V airport from 2010 to 2018

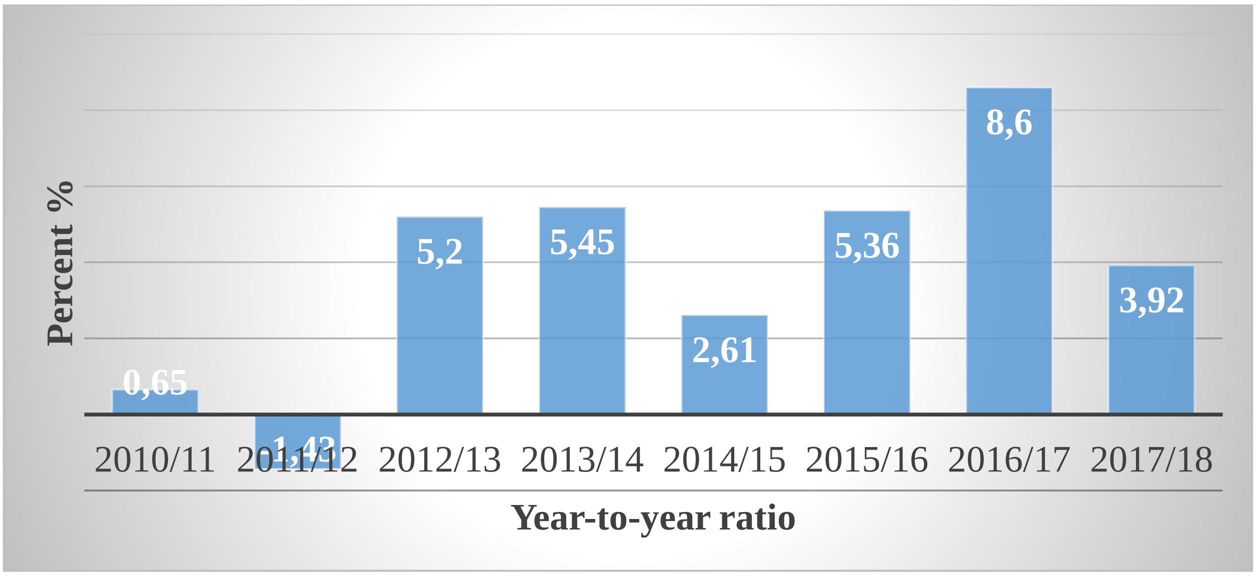

Fig. 2.2. Diagram of passenger traffic year-to-year changes in % of Casablanca Mohammed V airport from 2010 to 2018

As we can see from figures 2.1 and 2.2, passenger traffic of Casablanca airport from 2010 to 2018 has stable trend to year-to-year growth. The number of passengers increases from approximately 7,2 million in 2010 to approximately 9,7 million in 2018. The growth for this period is approximately 35%.

Only one period the year-to-year ratio was negative: in 2011/12. Then we can see growth with lower limit 0.65% in 2010/11 to upper limit 8.6% in 2016/17.

Table 2.5

Cargo transportation volumes of Casablanca Mohammed V airport for 2005-2018 years period

Year	International, kg	National, kg	Total, kg
2005	49 890 878	5 957 351	55848229
2006	54 977 104	5 695 138	60672242
2007	60 708 330	6 072 792	66781122
2008	57 182 147	5 702 821	62884968
2009	53 337 133	5 301 952	58639085
2010	50 903 137	4 153 761	55056898

2011	50 480 295	4 320 353	54800648
2012	48 694 217	3 080 389	51774606
2013	50 319 096	2 564 193	52883289
2014	51 666 744	2 481 433	54148177
2015	62 088 237	2 166 739	64254976
2016	66 527 388	1 908 848	68436236
2017	80 194 252	1 885 635	82079887
2018	86 268 961	1 940 687	88209648

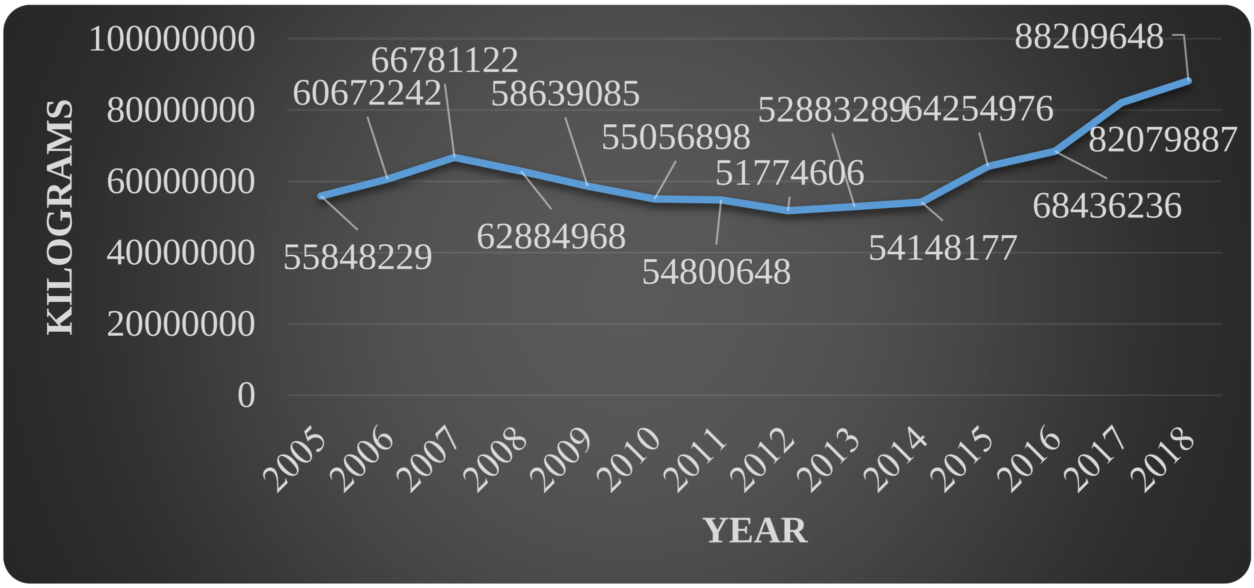

Fig. 2.3. Diagram of total cargo transportation volumes of Casablanca Mohammed V airport for 2005-2018 years period

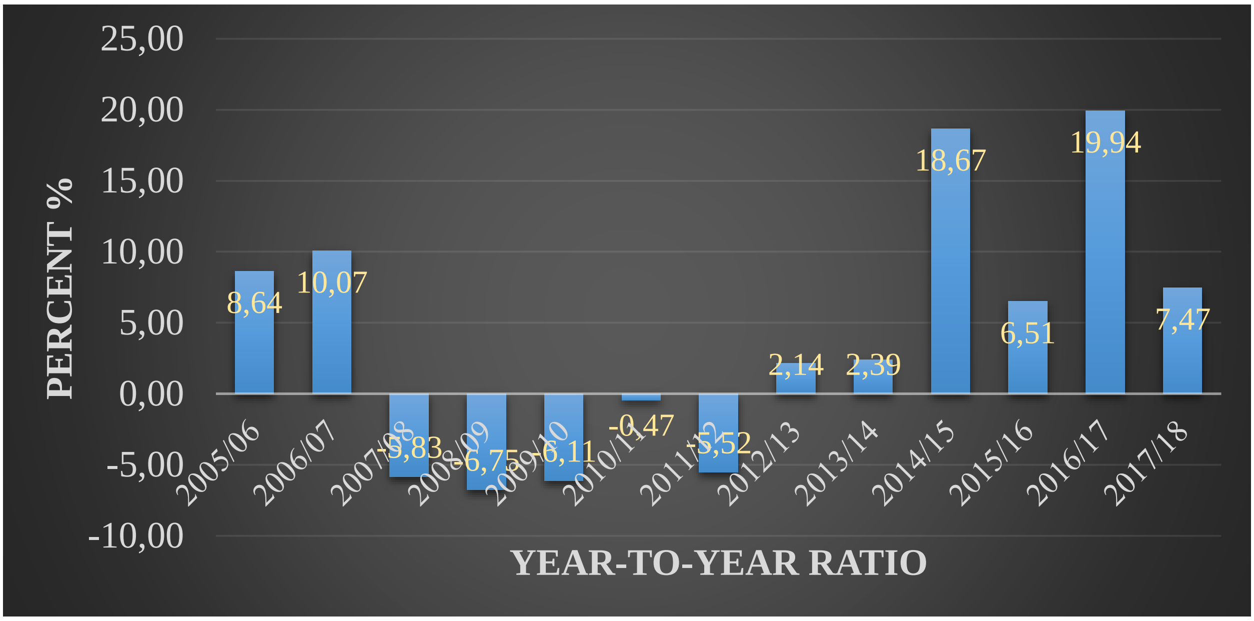

Fig. 2.4. Diagram of total cargo transportation volumes year-to-year changes in Casablanca Mohammed V airport for 2005-2018 years period

As we can see from figures 2.3 and 2.4, cargo transportation volumes in Casablanca Mohammed V airport have non-stable trend which tends to growth in general – from approximately 56000 tons in 2005 to more than 88000 tons in 2018.

Table 2.6

Cargo transportation volumes of Casablanca Mohammed V airport for January-September 2019 period

Month	International, kg	National, kg	Total, kg
Jan	7 031 267	163 551	7 194 818
Feb	7 123 046	114 225	7 237 271
Mar	8 049 597	171 147	8 220 744
Apr	8 752 390	180 086	8 932 476
May	9 519 422	158 135	9 677 557
Jun	7 288 522	144 926	7 433 448
Jul	7 691 342	148 769	7 840 111
Aug	6 244 258	118 292	6 362 550
Sep	6 675 389	255 031	6 930 420

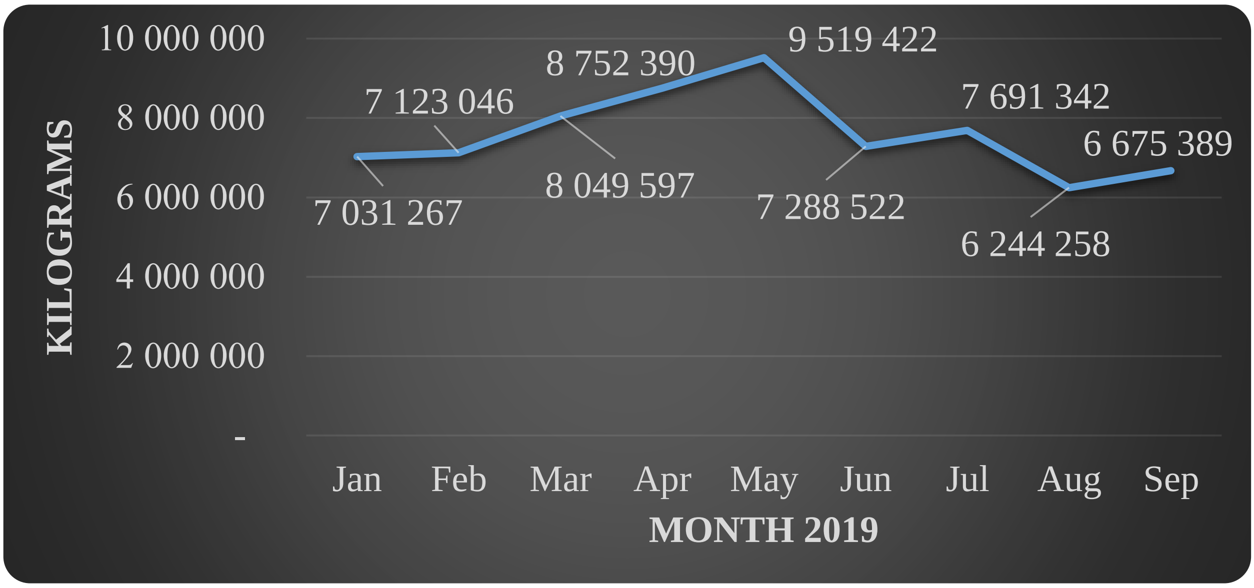

Fig. 2.5. Diagram of total cargo transportation volumes of Casablanca Mohammed V airport for January-September 2019 period

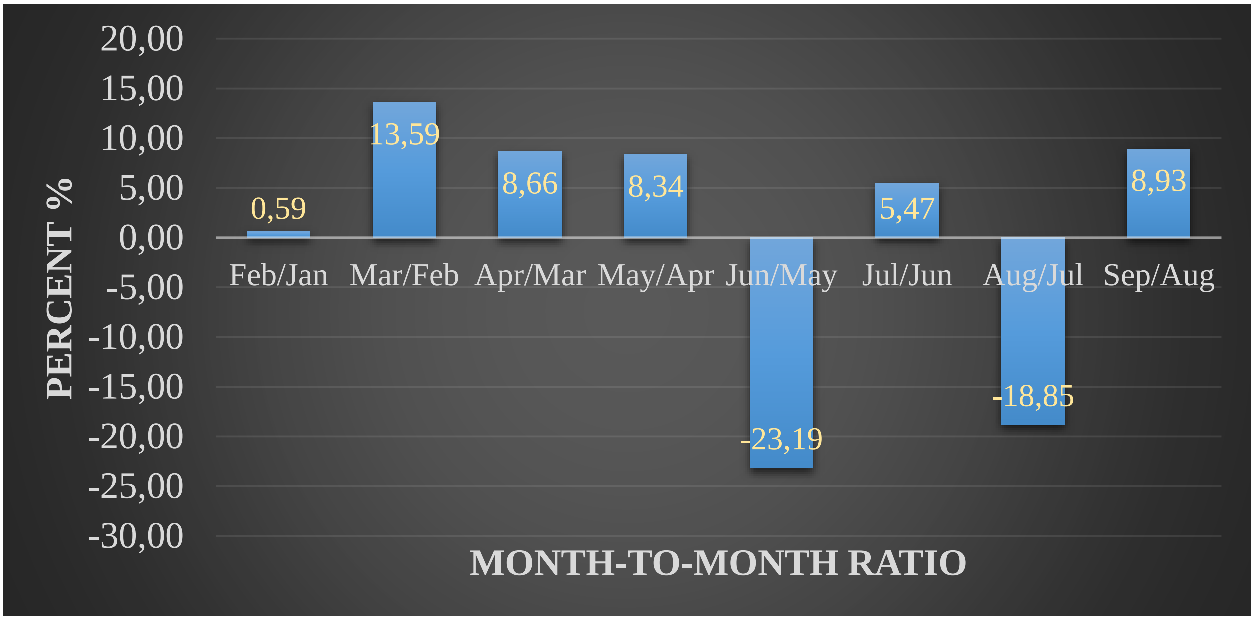

Fig. 2.6. Diagram of total cargo transportation volumes year-to-year changes in Casablanca Mohammed V airport for January-September 2019 period

As we can see, the total cargo transportation volumes year-to-year changes trend in Casablanca Mohammed V airport for January-September 2019 period is non-stable and non-linear.

2.3. Comparative analysis of statistical data for Casablanca Mohammed V airport and Kyiv Boryspil airport

Table 2.7

Passenger traffic of Kyiv Boryspil airport for 2005-2018 years period

Year	Passengers	Change
2005	3930000	24,1%
2006	4618000	17,6%
2007	5671300	22,7%
2008	6700000	17,4%
2009	5793000	13,0%
2010	6692382	15,5%
2011	8029400	20,0%
2012	8478000	5,0%
2013	7930000	6,5%
2014	6890443	13,1%
2015	7277135	5,6%
2016	8650000	18,9%
2017	10554757	22,1%
2018	12603300	19,4%

Table 2.8

Cargo transportation volumes of Kyiv Boryspil airport for 2014-2018 period

Year	Ton
2014	20120

2015	25000
2016	30064
2017	36891
2018	40100

We are able to compare statistical data for two airports only for the same periods. That is why we choose 2010-2018 period for passenger traffic comparation and 2014-2018 period for cargo volumes comparation. Results are shown on figures 2.7 and 2.8.

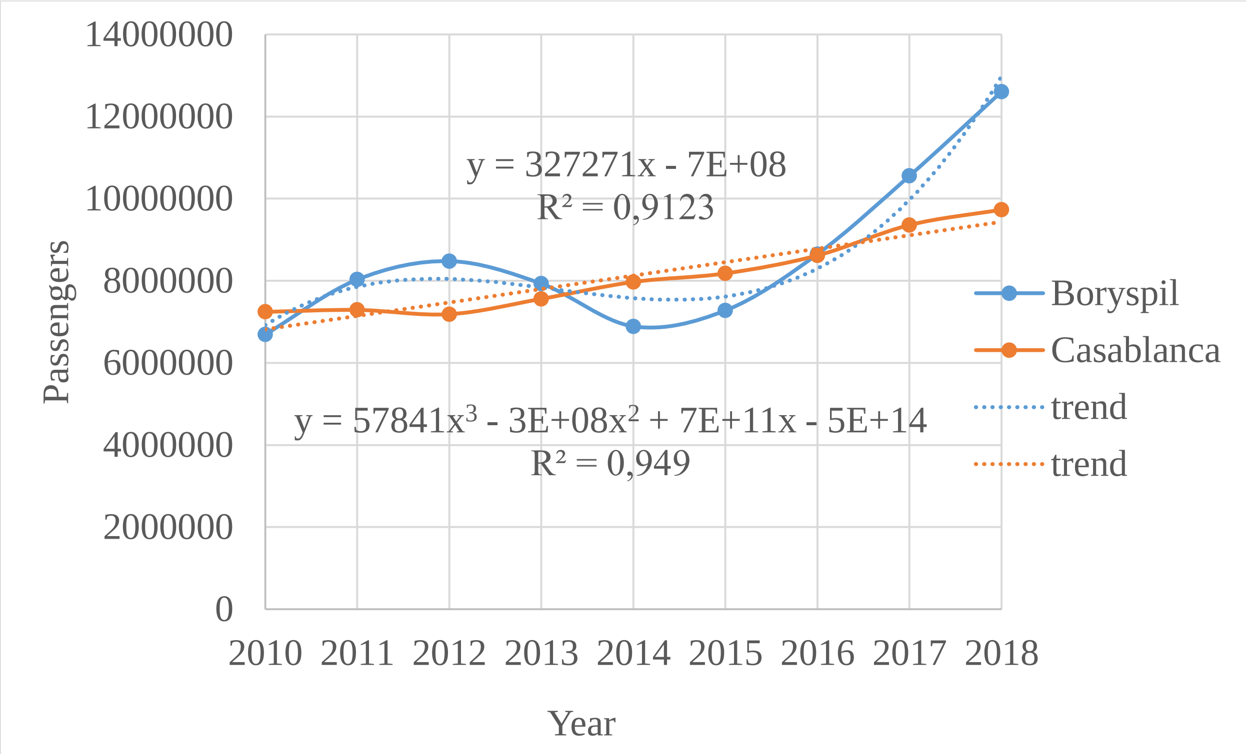

Fig. 2.7. Comparative diagram of passenger flows statistical data 2010 - 2018 for airports Casablanca and Boryspil

Comparative graphs of passenger traffic statistical data 2010 - 2018 for airports Casablanca and Boryspil are presented on fig. 2.7. As we can see, passenger traffic for Casablanca airport from 2010 to 2018 has stable trend and can be easily approximated by the line with very good fit (correlation coefficient is higher than 0,9). As for Boryspil airport – passenger traffic growth is non-linear and can be approximated by 3th order polyoma with good fit.

As for number of passengers – in 2010, 2014 and 2015 years Borispil has lower passenger flows compare to Casablanca airport, in 2016 – approximately the same and in 2011,2012,2013, 2017 and 2018 years – higher passenger traffic compare to Casablanca airport.

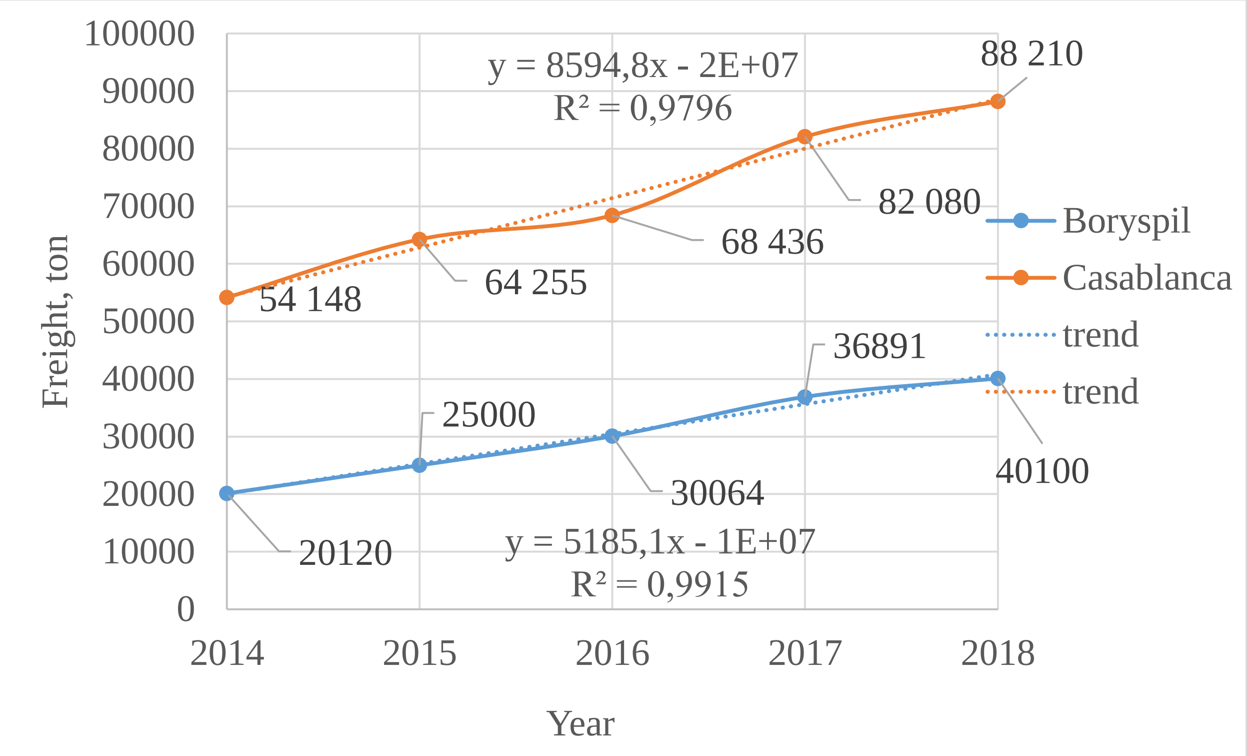

Fig. 2.8. Comparative diagram of cargo flows statistical data 2014 - 2018 for airports Casablanca and Boryspil

Comparative analysis of cargo flows statistical data 2014 - 2018 for airports Casablanca and Boryspil is presented on fig.2.8. As we can see, cargo flows for Casablanca airport more than 2 times higher for each year.

All trends are stable and can be easily approximated by the line with very good fit (correlation coefficient is higher than 0,9).

3. DESIGN PART

Air Transportation Management Department				NAU 20. 09. 99. 300EN			
Done by	Maghraou M			3. DESIGN PART	Letter	Sheet	Sheets
Supervisor	Yun G.				D	75	35
St. Inspector	Yulia V.Shefchenko				FTML 275ОП-.202Ma		
Head of the Dep.	Yun G.						

3.1. An integrated software platform for airport queues prediction with application to resources management

This thesis deals with the proposal of an integrated service platform to (i) efficiently manage the airport resource and (ii) maximize the passengers satisfaction, as explained in Fig. 1. The platform architecture is modular and integrates several components, among which:

- Operational Control Center (OCC) is in charge of collecting data by different Airport systems and performing the data aggregation with its exchanging in an automated way. Information is provided to both Airport Operator and Passenger via a Graphical User Interface (GUI) with different access levels;
- Queueing Control Module (QCM) which applies queueing theory approaches to predict the time to be spent waiting in line at the security control system on the basis of additional information pro-vided by external modules. The QCM data can be also sent to the OCC in order to perform decision support process.
- Resource Management System (RMS) is in charge of the monitoring and optimizing resources assignment according to predefined policies; it accepts as input the information related to the resources status, including queue data.

The focus here is on the design of the QCM by proposing a suitable queueing analytical approach. Additional information, originating from the OCC and RMS, could be provided to the decision support process in order to improve the estimation accuracy of the waiting time at the security control lane, making it close to the actual value. Towards this end, two suitable parameters, named queue disposal time and actual queue waiting time are introduced. Specifically, we adopted an advanced queueing theory approach Kleinrock (1975), in order to obtain waiting time predictions as close as possible to the real values. The accuracy of this approach will be validated by providing comparisons between analytical predictions and actual values.

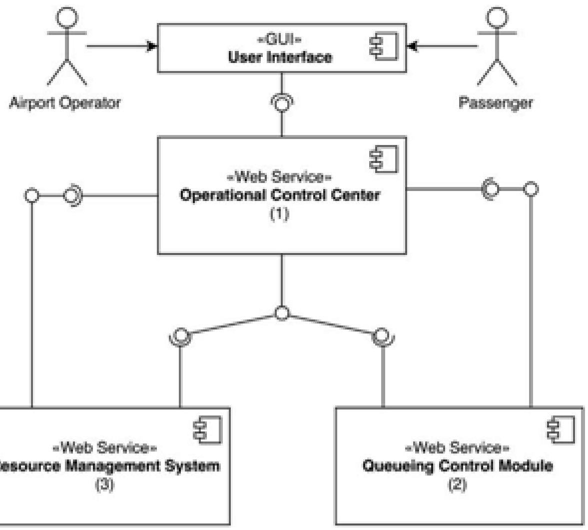

Fig. 3.1. The figure depicts the way components are logically connected.

The system pro-vides customize User Interfaces according to access levels. All components are implemented as Web Services. The OCC (1) module has in charge the decision process. It collects data from airport systems and shares them with the other modules. The QCM (2) receives the queue data in order to forecast the parameters of interest. The predictions are sent to OCC that uses the RMS (3) to control and optimize the resources assignment.

3.1.1. Related works

Queuing theory based methods have been widely investigated and applied in several scientific fields, as operation research and computer networks. Recently, queuing theory has been successfully adopted to address several airports features. The vast majority of the scientific literature uses queueing theory as a modeling method by limiting to Poisson arrival distribution. In particular, the M/M/c queue model has been widely applied in characterizing the check-in process Bevilacqua and Ciarapica (2010); Kierzkowski and Kisiel (2015) as well as the passengers security screening process Gilliam (1979). An interesting case study is represented by the Monastir Habib Bourguiba Interna-tional Airport Mehri et al. (2008), for which a M/M/c model was considered Kierzkowski and Kisiel (2015). Nevertheless, after 9/11 and terrorist threats, the increasing complexity of the airport management makes the M/M/c approach oversimplified, and it is not appropriate in providing accurate predictions in several practical situations, due to the lack of the memoryless property regarding the passengers arrival process Schultz et al. (2010); Paxson and Floyd (1995).

Unfortunately, the application of advanced queueing theory methods to support an efficient security control service planning and management, involves practical considerations and specific additional efforts, that sometimes makes it extremely complex, due to the presence of multiple servers and non trivial passengers arrival processes. This at first sight seems to favor simulation based methods van Dijk (2002); actually, the adoption of computer simulation methods present numerous drawbacks, e.g., they require big data input and an in-depth analysis of the passengers arrival process Robertson et al. (2002), including sociological aspects. Briefly, the simulation techniques, though attractive, are suited only if the equivalent analytic approach complexity is not affordable to be adopted.

The aim of this paper is to propose a low complexity queueing theory based method capable of correctly predicting several service indexes related to the airport security checkpoint, and, hence, re-presenting a suitable alternative to any simulation based approach. As first result of our analysis, we show that the passengers arrival process related to a data collection campaign cannot be considered as memoryless. As a consequence, the more general M/M/c queueing model has to be considered. Hence, with the aim of overcoming complexity impairments without loosing the analytic predictions accuracy, we propose here to adopt an equivalent M/M/1 model, where the server works c time faster than in the M/M/c case. Comparisons between the obtained analytical predictions and actual data will be provided in order to validate the goodness of our assumption.

3.1.2. Queueing system model

At the airport security checkpoint, customers (i.e., passengers), after a successful ID and boarding pass checking, also performed in parallel lines, join an unique input line, before accessing the parallel Security Control Counters (SCCs), i.e., body scan and X-ray scan servers. It is worth noting that the arrivals flows, from individual ID and boarding pass checking lines, merge together to became an unique flow at the input line. Customers departure from the input line, according to the First Come First Served (FCFS) policy to joint a small queue to access the SCC service after arranging the baggage control. For the overall arrival process at the input line, we assume that the customers interarrival times have a general distribution and denote with A (t) the associated generic probability density function (pdf), characterized later by means of a suited statistic fitting.

Likewise, we assume the customers service time at a SCC as the time elapsed from the departure instant of a queued customer from the input line to the instant of security control completion (i.e., departure from the system). Customers are served on an individual basis, according to the arrival order (FCFS policy). Moreover, the service time of a given customer generally does not influence the service time of whichever customer: this highlights a sort of memoryless property. As a consequence, the passenger service process can be modeled as a stationary exponentially distributed process Ω, defined as:

$$\{\Omega(t): t \geq 0\} \tag{3.1}$$

where $\Omega \sim$ Exponential(μ), with μ the mean service time and $\lambda \doteq 1/\mu$, the resulting mean service rate.

3.1.3. Analytical model

From the above considerations, it follows that the security check-point can be modeled as a M/M/c queueing system with c independent servers (i.e., SCCs) that work in parallel. The passengers are waiting in line (queue) to access the first available server according to the FCFS policy. It is well known from the standard queueing theory, that the complete analysis of a M/M/c queueing system is too complex to be carried out in a closed form. Hence, with the aim at maintaining the attractive features of analytical approaches with respect to the simulation alternatives, we have resorted here to the simplifying assumption of analyzing a M/M/1 system, named hereafter as equivalent M/M/1 system, where the server is c time faster with respect to any server of the M/M/c case Whitt (2002). With the aim at justifying the accuracy of our assumption, we stress that it is well known from the standard queueing theory that a M/M/c and a c time faster M/M/1 systems have the same behavior for what concerns the prediction of the time needed for a given passenger to reach the head of the arrival queue when all the servers are busy, that is the case study of interested here. Note (see Algorithm 1) that whenever a passenger asks to the platform to evaluate the expected waiting time when one of more servers are idle the answer is conventionally set to 0.

As known from standard queueing theory, the imbedded Markov chain approach can be adopted to analyze this equivalent M/M/1 queueing system Kleinrock (1975); Kendall (1953). The accuracy of this method will be validated by comparing the obtained analytical predictions with actual data. In our case, the imbedded points are represented by the passengers arrival instants at the input line. As a consequence, by observing the queue state (i.e., the number of passengers in the input line) at the time instant in which a passenger enters the queue, the Markov property is satisfied and the queue length evolution can be described through the Lindley's recursion equation Lindley (1952):

$$\begin{aligned} &q_{n+1} = (q_n + 1 - c_{n+1})^+, q_n \in N \\ &c_{n+1} \le q_n + 1 \end{aligned} \tag{3.2}$$

where q_n is the number of passengers waiting in the queue just before the arrival at the n-th time instant, c_{n+1} is the number of passengers that left the queue in the between two consecutive arrivals (i.e., the $n + 1$-th and n-th time instants), and the operator $(\chi)^+$ is defined as $\max(0, \chi)$.

Recalling that the system state is represented by the number of passengers in the queue at the imbedded time instants, under the assumption of the existence of a steady-state regime, the one step transition probability P associated to the queue length process results:

$$P \doteq \begin{pmatrix} p_{0,0} & p_{0,1} & 0 & 0 & 0 & \cdots \\ p_{1,0} & p_{1,1} & p_{1,2} & 0 & 0 & \cdots \\ p_{2,0} & p_{2,1} & p_{2,2} & p_{2,3} & 0 & \cdots \\ p_{3,0} & p_{3,1} & p_{3,2} & p_{3,3} & p_{3,4} & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix} \tag{3.3}$$

where we have:

$$p_{k,k+1-j} \doteq \Pr\{q_{i+1} = k+1-j \mid q_i = k\} = \int_{t=0}^{\infty} \frac{(c\lambda t)^j}{j!} e^{-c\lambda t} a(t)dt, \forall k < j \tag{3.4}$$

In (3.4), the term λ^{-1} denotes the mean passenger service time at a security control counter, c is the number of open SCCs (i.e., servers) and *a* (t) denotes the passengers interarrival probability density function (pdf) in a generic form. The resulting Markov chain associated to the process in (2) is shown in Fig. 3, where, for the sake of notation simplicity, we defined: $\beta_j \doteq p_{k,k+1-j}$, see Eq. (3.4), and:

$$p_{j,0} \doteq 1 - \sum_{i=0}^{j} \beta_i \tag{3.5}$$

The proposed Congestion Control Policy (CCP) is based on the evaluation of the mean value of the time needed to have a number of passengers in the security desk system lower than a specified threshold value, L. In particular, being L_a the number of actual costumers waiting in queue when the customer asks the system, the expected number L specified by the customer has to satisfy this condition $0 \le L \le L_a$. This time interval, normalized to the mean interarrival time, is named, in what follows, as queueing disposal time, ($T_d > 0$). It easy to verify that, under a given passengers load condition, the T_d value decreases if the number of servers c increases.

Note that the T_d value is equal to zero (no congestion) if the observed number of passengers in the security checkpoint is not greater than L. According to this, we can collapse all the states having a value not greater than L into a unique macro state and considering it as the absorbing state (as) of our process. Hence, we can resort to the use of the Absorbing Markov Chain (AMC) approach by distinguishing between the as, which once entered cannot be left, and all the other possible queue states named transient states, which once entered can be left Kemeny et al. (1960).

According to its definition, the T_d value is given as number of steps needed to reach the as, starting from a given transient state (i.e., re-presenting the observed number of passengers in the security check-point). As a consequence, the one step $(L_a - L) \times (L_a - L)$ transition matrix $\hat{P}$ results to be:

$$P \doteq \begin{pmatrix} \sum_{k=0}^{L} p_{L,k} & p_{L,L+1} & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \sum_{k=0}^{L} p_{j,k} & p_{j,L+1} & \cdots & p_{j,j+1} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \sum_{k=0}^{L} p_{La,k} & p_{La,L+1} & \cdots & \cdots & \cdots & p_{La,La} \\ 1 & 0 & 0 & 0 & \cdots & 0 \end{pmatrix} \tag{3.6}$$

where the $(L_a - L - 1) \times (L_a - L - 1)$ sub-matrix Q, whose entries are the transition probabilities between transient states, can be expressed as:

$$Q \doteq \begin{pmatrix} p_{L,L+1} & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ p_{j,L+1} & \cdots & p_{j,j+1} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ p_{La,L+1} & \cdots & \cdots & \cdots & p_{La,La} \end{pmatrix} \tag{3.7}$$

According to the standard AMC theory we have to derive the fundamental matrix N as:

$$N \doteq (I - Q)^{-1} \tag{3.8}$$

Hence, the vector t can be derived as:

$$t \doteq N1 \tag{3.9}$$

where 1 is a length-t column vector whose entries are all. From (3.9) we have that the i-th entry of vector t gives the parameter T_d, which indeed represents the expected number of steps needed before entering the as (i.e., absorbed) when starting from the transient state corresponding to i-th entry. The effectiveness of the proposed method is highlighted in the next part of this research, by focusing on a specific case study. Moreover, in the same part, the obtained analytical predictions are validated by comparisons with real data retrieved by a measure campaign carried out in an actual airport.

3.1.4. Case study

The case study under consideration is represented by the Casablanca Mohammed V International Airport that is the main Morocco airport in terms of number of passengers. It operates seven days a week. The airport map is shown in Fig. 3.4, where the security control area is highlighted.

At the light of the positive trend of the passenger volume growth the local AO is particularly interested in developing and applying an integrated management platform and a queue modeling tool to manage the passenger flows.

As shown in Fig. 3.2, passengers arrive into the system and, after a successful ID and boarding pass check, they join the input line.4 As soon as a passenger approaches the head of the unique queue, he/she is redirected directly to the proper checkpoint, where he/ she enters a second additional small queue needed to arrange his/her hand baggage. However, as it happens case study, the time spent in the second queue could be neglected due to the majority of low cost flights with light (or even without) hand baggage. In addition several assistants suggest in advance how to prepare baggage before security check, so that the overall time spent in the small queue can be assumed with good approximation only due to the time needed to accomplish the body scan and security screening operations.

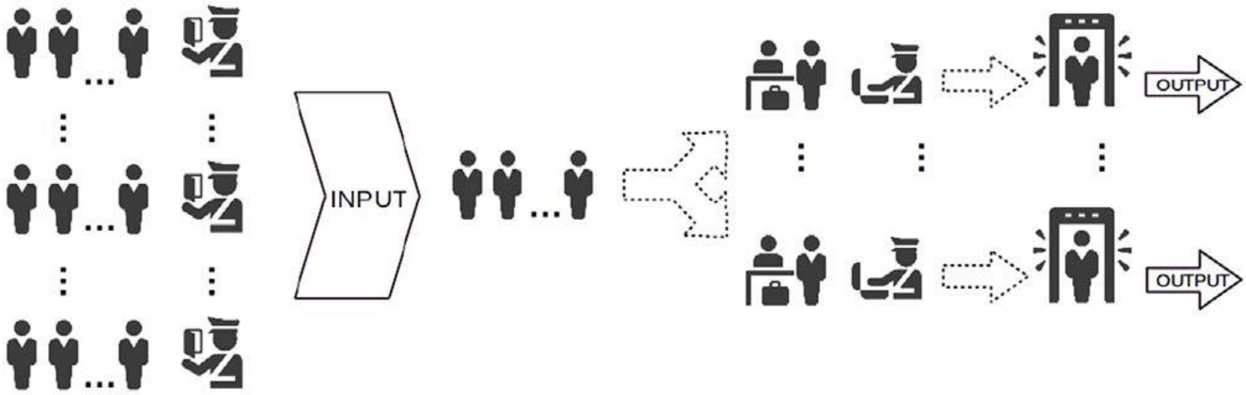

Fig. 3.2. Queueing system model assumed for the security checkpoint, detailing the operations involved in the security check procedures.

Thanks to this platform, all the systems of the airport structure will be manageable in an integrated way, from flights and passengers to baggage and human resources. Moreover, new project aims at allowing passengers to interact with the airport, by means of smart-phones, in order to acquire as much information as possible regarding the level of satisfaction of final user, and increase the satisfaction of passengers.

The platform architecture is open and integrates several modules, among which RMS and the QCM, as depicted in Fig. 3.1. The modules integration allows to increase airport efficiency by handling complex decision making processes.

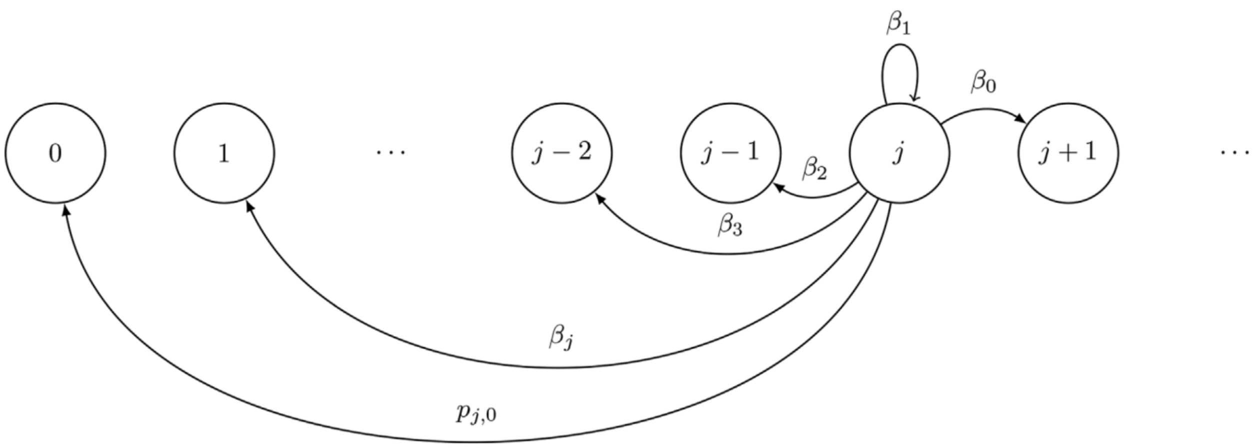

Fig. 3.3. Representation of queue length process by Embedded Markov Chain starting from the state q_n = j. Since the queue system is observed when a passenger arrives, the state can not increase more than one between two consecutive arrivals. This fact is represented by the right transition denoted with β_0, i.e., the probability that zero passengers are served. In general, a transition labeled with β_i, $i \in 0, \ldots, j + 1$ represents the probability that exactly i passengers are served between two consecutive arrivals; β_i are obtained by (3.4).

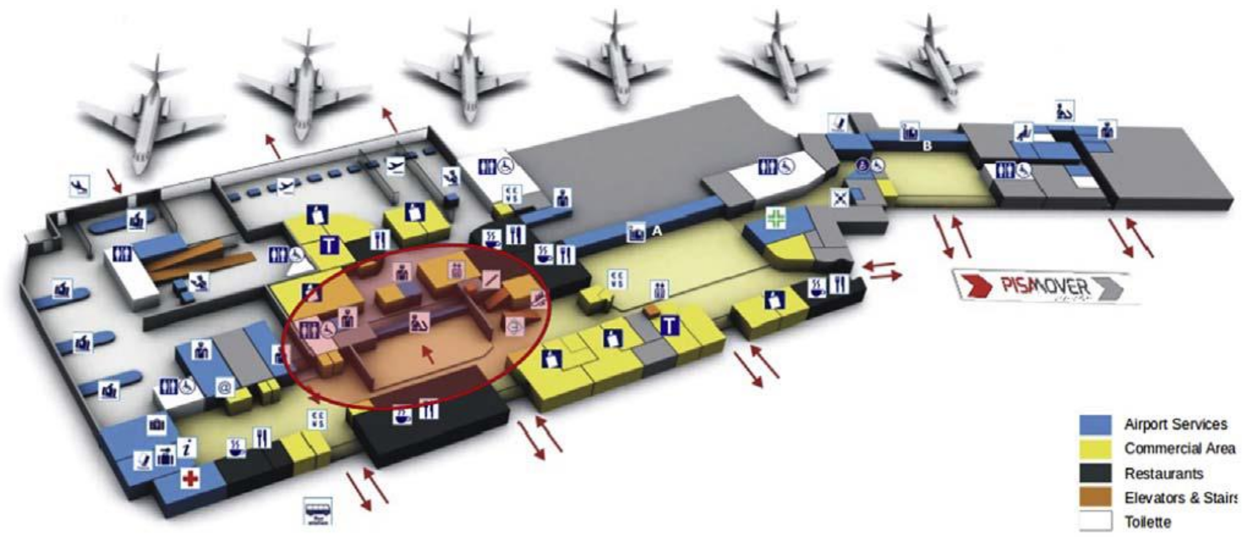

Fig. 3.4. Map of airport ground floor, including the security control area (delimited by a red circle). (For interpretation of the references to colour in this figure legend.)

3.1.5. Software architecture and design

The analytical model, has been developed during the framework of the Innovative Technologies and Processes for Airport Management Project (PITAGORA), supported by the European Regional Development Fund (ERDF) program. The project goal is to design, develop and test an innovative platform that integrates heterogeneous systems with the scope of increasing airports efficiency. In particular, the local AO is interested in adopting the provided services for the following aspects:

- flight efficiency;
- baggage management;
- increased security management;
- accidents prevention and resolution;
- resources management.

The complexity of the airport system is also due to the large number of stakeholders operating in the same geographical area, but with different responsibilities, while using different support systems. As a matter of fact, an airport can be characterized as a collection of processes providing each other facilities for the correct implementation of airport operations. According to this view, PITAGORA platform is developed as a system of systems, allowing integration of heterogeneous modules developed by different companies. Thus, the platform is engineered as Service Oriented Architecture (SOA). The main concepts of SOA are services and interfaces Erl (2005). A system service is a self-contained business functionality provided to the other systems through an interface and consumed by a communication protocol over the network.

In order to allow system interoperability, extendibility and flexibility properties, the implementation follows the Web Service (WS)s approach based on the following technologies:

- XML Schema Definition (XSD): defines the data structure used;
- Web Services Description Language (WSDL): contains services and communication interfaces definition;
- Simple Object Access Protocol (SOAP): over HTTP as messaging protocol layer.

A software component implements a web service as defined in the WSDL file: this service exposes several interfaces, dedicated to a specific task. Another component may use the WSDL to implement the software that calls the service and uses one or more interfaces. Software components may send/receive events and commands and exchange data as defined in the XSD files. Since all communications with and between WSs contain sensitive data, also security issues have to be taken in to account. The PITAGORA platform, indeed, implements best practices to secure a WS and avoid possible attacks. The module is integrated in the PITAGORA platform through SOAP request on HTTP Secure (HTTPS), then only secure communications are allowed.

The QCM module permits to estimate (i) the overall time a passenger has to spend in screening queue and (ii) the time needed to reach a pre-defined queue length. The systems also takes in account the number of SCCs expected to be jointly active. The QCM forecasts the previous parameters based on the equivalent

M/M/1 queuing theory model introduced in the previous Section. In particular, if all the c SCCs are busy, the QCM returns:

- the actual queue waiting time, T_w;
- the queue disposal time, T_d;
- the predictions based on different number of active Security Control Counter (SCC)s in order to satisfy the Quality of Experience (QoE) target value (i.e., T_d lower than a selected threshold, Θ).

In particular, the predicted T_w value is given as a response to a direct customer query. It is assumed that at the query instant, the interested customer virtually joins the security check system queue, where j customers are waiting in line at the security checkpoint for service. As a consequence of the assumed FCFS policy, the exponentially distributed security checking service time and of the assumed equivalent M/M/1 model, the resulting overall time that the virtual customer spends in the security check system is the summation of j i.i.d. service times τ_i, with $1 \leq i \leq j$, whose mean value is:

$$T_w = \begin{cases} \overline{j\tau}, \; j > c \\ 0, \; j \leq c \end{cases} \tag{3.10}$$

where τ represents the mean value of the security check service time per customer according to the equivalent M/M/1 model.

In addition, a customer can request a mean queue waiting time prediction to the QCM, i.e., the time to be spent waiting for service by assuming to arrive at the security check service after a certain delay t. By considering the mean number of transitions that occurs in t, namely $\bar{k}$, as:

$$\bar{k} = E\left[\frac{\Delta t}{A_n}\right] \tag{3.11}$$

it is possible to predict the future queue state vector $\pi^{(k)}$, once the actual queue state, i.e., the number of waiting customers $\pi^{(0)}$, is known, where $\pi^{(0)}(j) = 1$. In particular, we have that:

$$\pi^{(\bar{k})} = \pi^{(0)p\bar{k}} \tag{3.12}$$

Then, the expected mean queue length $q_{\bar{k}}$ is computed according to standard theory Kleinrock (1975). Finally, the expected mean waiting time is derived by (3.10) where j is replaced by $q_{\bar{k}}$.

The predictions are evaluated by QCM that provides two services to the PITAGORA platform:

- publish() web service;
- getQueueForecast() web service.

The first service is presented in Fig. 3.5. The platform automatically provides the QCM with the passengers presentation patterns at each screening queue and the number of security check points expected to be active by using the publish() service. To complete the task, QCM records both the prediction and actual screening queue holding time values, re-turning them to the platform. The second service is designed as a request-response pattern, as pointed out in Fig.3.6. Similarly, the platform calls the QCM service getQueueForecast() to get queue forecast at the varying of the number of servers (i.e., security check operators). It is worth noting that the output of the both update() and compute() methods depends on the difference between the actual number of passengers in the queue and the number of actual or expected security check operators.

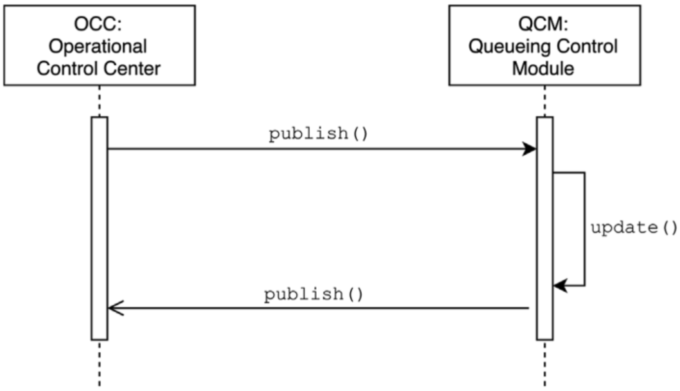

Fig. 3.5. UML sequence diagram of the first scenario, starting from the OCC calling the publish() service provided by the QCM. After that, the QCM updates the queue state and returns to OCC the forecasted data.

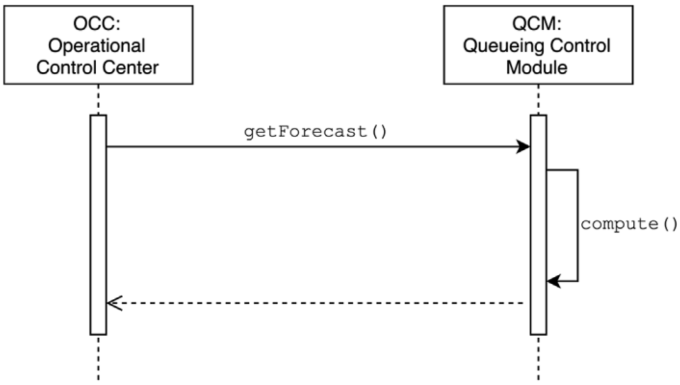

Fig. 3.6. UML sequence diagram of the second scenario, starting from the OCC calling the getForecast() service provided by the QCM. The OCC ask QCM to compute a forecast based on a different number of open SCCs.

Moreover, in order to easily access the queue information, a web user interface has been developed. The web application design uses the Model-View-Controller (MVC) pattern Krasner et al. (1988). The integration between QCM and OCC uses enterprise integration patterns through messaging Hohpe and Woolf (2003).

Fig. 3.7 depicts the modules interactions in the CCP and in the disposal time prediction. In particular, the flowchart represents the CCP algorithm design and the QCM role in the decision support process. As the QCM receives from OCC the number of open and active SCCs (i.e., SCC and SCCa, respectively) and the new arrived passengers, it updates the queue state Q_n and the open SCC number. Consequently, the queue disposal time is computed and collected into a prediction list. The procedure for evaluating T_d is further detailed in Algorithm.

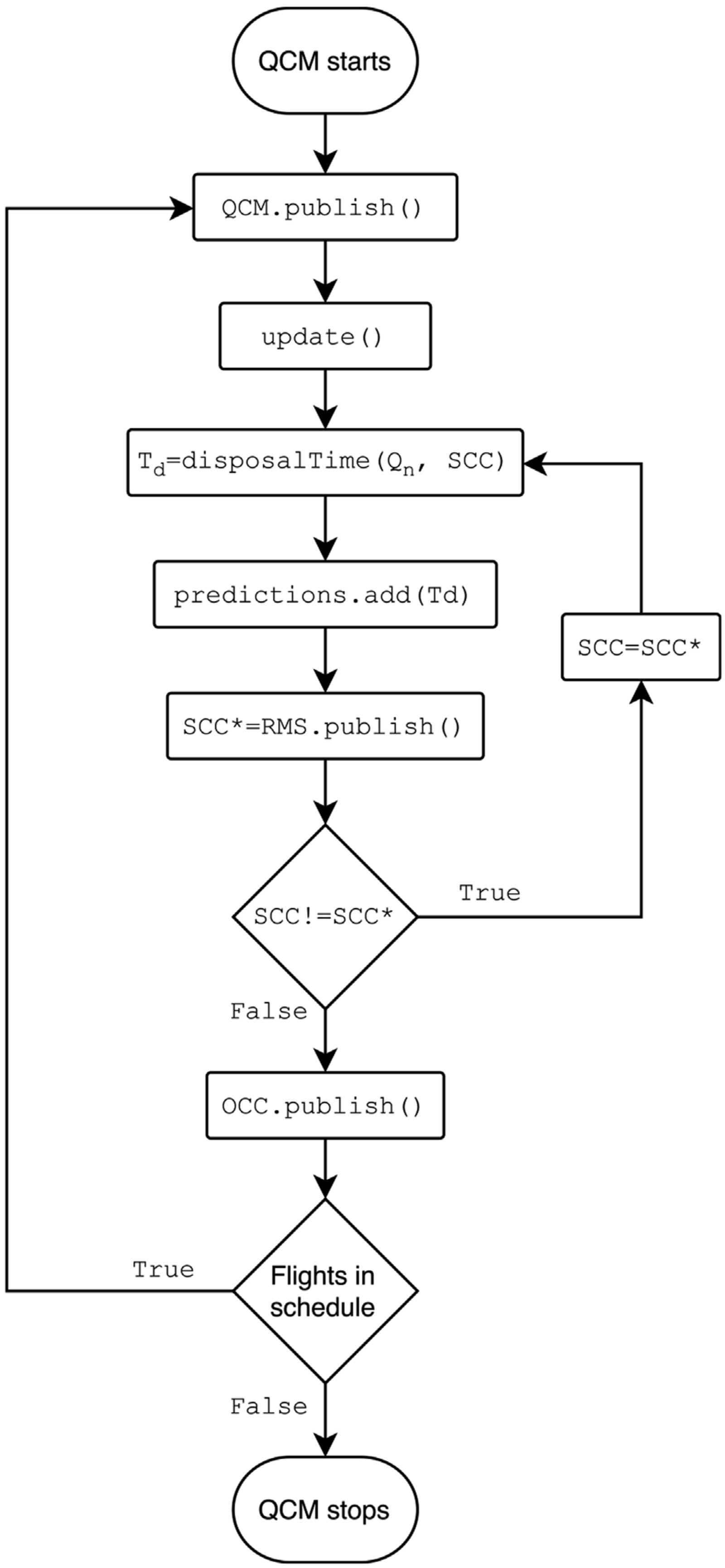

Fig. 3.7. TCCP algorithm design and the QCM role in the decision support process.

The predictions are sent to RMS that is in charge of optimizing re-sources assignment. RMS indicates to QCM the optimal number of SCCs (SCC∗) that may be used to keep under control the queue state. Therefore, if this parameter is different from the actual number SCC, the QCM uses SCC∗ to perform a new disposal time prediction, which is also collected into prediction list. At the end of procedure, the predictions are sent to OCC through the publish() web service in order to perform decision support process.

3.1.6. Passenger arrival process

The modeling of the overall queueing system shown in Fig. 3.2 requires the characterization of the arrival and service processes. In particular, the former one relies on a data collection campaign. This has been performed by recording the passenger (i.e., customers) entry time at the security check lane for a whole day. To refine the statistic, data collection has been performed over five consecutive days. The range of inter-arrival times observed is between 0 and 1450 [s]. The statistical fitting procedure has been performed by means of MATLAB statistical toolboxes MATLAB (2016); in particular, the Maximum Likelihood Estimation (MLE) method has been applied to estimate the main statistical parameters. Fig. 8 depicts the interarrival time distribution function in the range [0 ÷ 100][s]. The vast majority of inter-arrival times takes small values, however, higher vaues also occur. In Fig. 2.9, the inter-arrival time histogram with the probability distribution resulting from the statistical fitting is presented. In particular, we have that, with a good agreement, it follows a log-normal distribution:

$$N(\ln t, \mu, \sigma^2) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(\ln t - \mu)^2}{2\sigma^2} \right] \tag{3.13}$$

with location parameter μ and scale parameter σ^2. Thus the passengers inter-arrival process $A(t) \sim N(\ln t, \mu, \sigma^2)$ results to be heavy-tailed distributed.

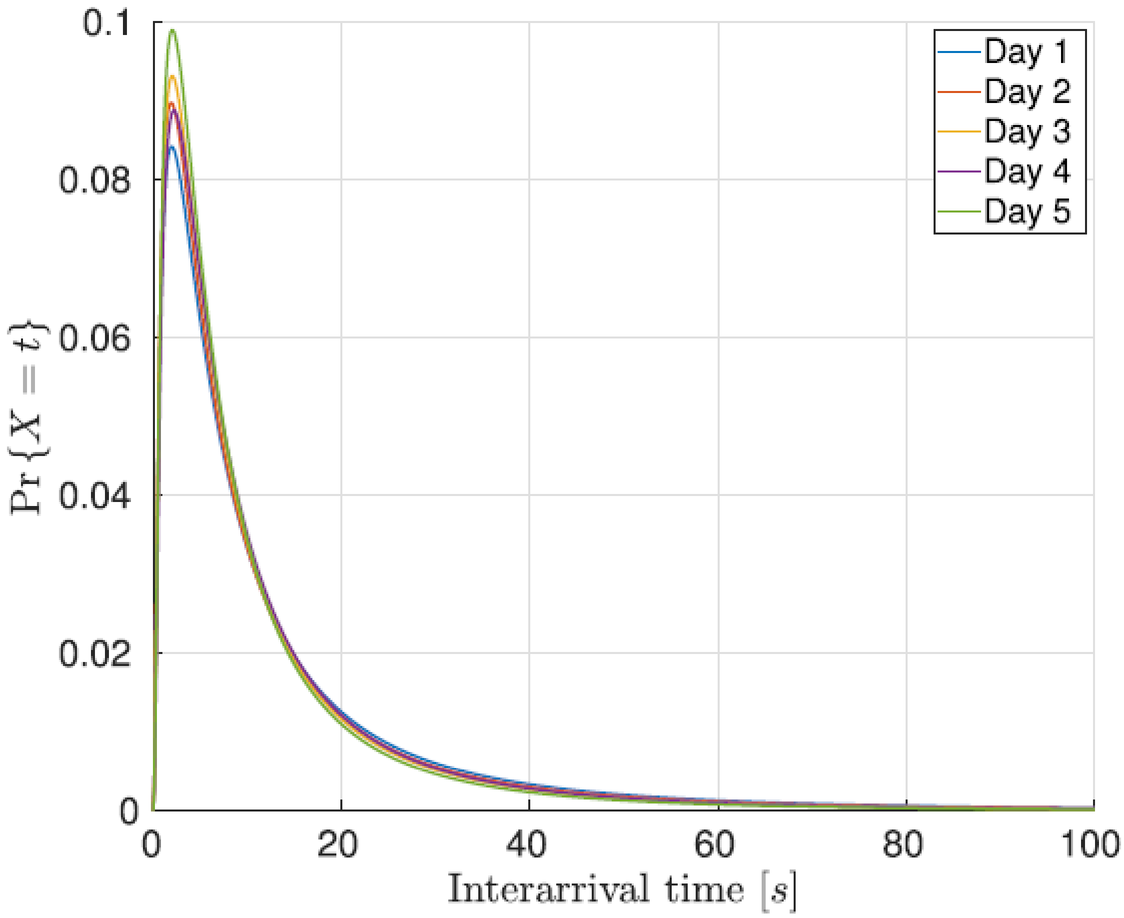

Fig. 2.8. Interarrival time distribution functions $N(\ln t, \mu, \sigma^2)$ for each day of dataset. It is worth noting that the interarrival process follows the same distribution function.

Moreover, the presence of a Long-Range Dependence LRD structure within the passengers arrival process can be pointed out according to the "pictorial proof", introduced in Leland et al. (1994) and shown in Fig. 2.10. A more rigorous proof can be provided by evaluating the Hurst parameter; specifically, two techniques, previously proposed in the existing literature on this subject Simonsen et al. (1998); Hurst (1951), have been applied. Both methods converge to H = 0.73, and being this value in the range of (1/2,1) it implies a LRD property.

3.1.7. Service process

The statistics of service process is obtained through the evaluation and fitting of passengers data collected in the Pisa airport by means again of MATLAB statistical MLE toolbox. Due to privacy restrictions, the data is not annotated with destination flight or other passengers personal information, thus allowing a quite generic model. The distribution closest to the collected data is the exponential one with mean service time μ_s = 20.3[s]. Since more than one SCC can be active, the service time pdf is

$$f_s(t) = \frac{c}{\mu_s} \exp\left[-\frac{c}{\mu_s} t \right] \quad (3.14)$$

where c is the number of open SCCs. Therefore, the service could be assumed as exponentially distributed.

Table 3.1

Summary results of waiting time. The values in first column are the number of open SCCs. The second reports the mean value of waiting time and the last column reports the mean relative error of waiting time prediction.

#SCC	*Tw* [*s*]	*Er* [*s*]
2	545.34	11.53%
3	90.36	16.45%
4	63.69	16.94%

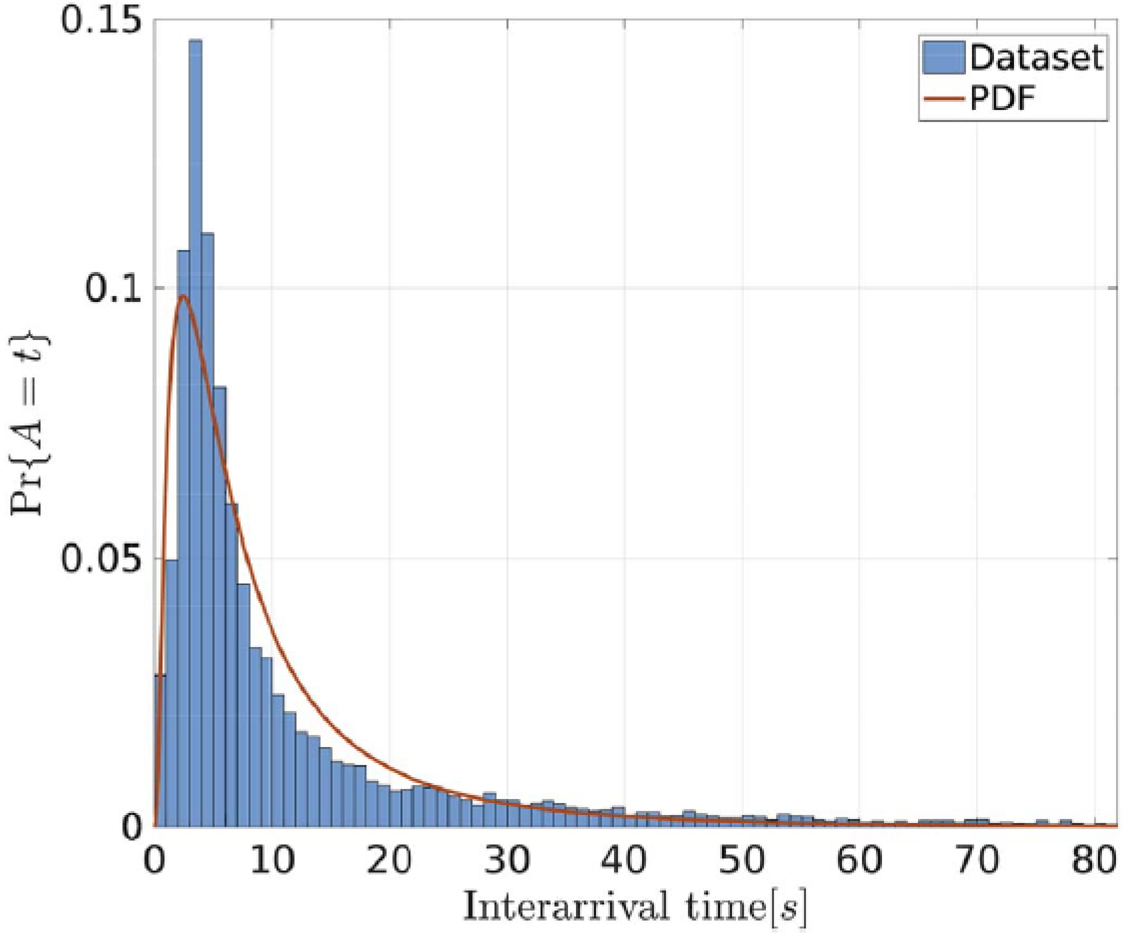

Fig. 3.9. Histogram of interarrival time obtained from 5 time series data. In red is depicted the log-normal distribution function $N(\ln t, \mu, \sigma^2)$ with mean value equal to 10.83 [s] that better fit the histogram. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.1.8. Results analysis

In the following the performance analysis of the QCM predictor has investigated by testing it over five operating days of the Casablanca airport. The focus is on a couple of queue parameters, that is the passenger waiting time T_w and the queue disposal time T_d, as below presented.

Passenger waiting time index

Parameter T_w is evaluated according to (3.10), under the assumption of knowing the current value of c and according to the equivalent G/ M/1 model. In order to verify the accuracy of our analytical predictions we have evaluated the mean value of the resulting estimation error E_r, defined as:

$$E_r = \left| 1 - \frac{T_w}{T_{w0}} \right| \tag{3.15}$$

where T_{w0} is the actual waiting time value.

The obtained results, in terms of mean value for both T_w and E_r , are given in Table 3.1 for different numbers of SCC. This Table highlights a good behavior of the proposed scheme resulting the mean value of E_r always less than 20% for all the considered cases.

A passenger can request the QCM to predict the future waiting time assuming that the passenger approaches the security checkpoint queue with a t delay from the request time instant. In our analysis we have reasonably assumed that t has values between 1 and 30 [min]. In Fig. 3.11 the predictions Mean Absolute Error (MAE) is presented for T_w (Δt). This figure highlight a good behavior of the proposed prediction algorithm, with MAE always lower than 1 min for all the possible values of t.

Queue disposal time

The model previously described is used to obtain an analytical prediction of T_d, according to (3.9). A threshold value Θ has been assumed for T_d, which is related to the target number L of passengers in the queue as:

$\Theta = L \cdot \mu s$

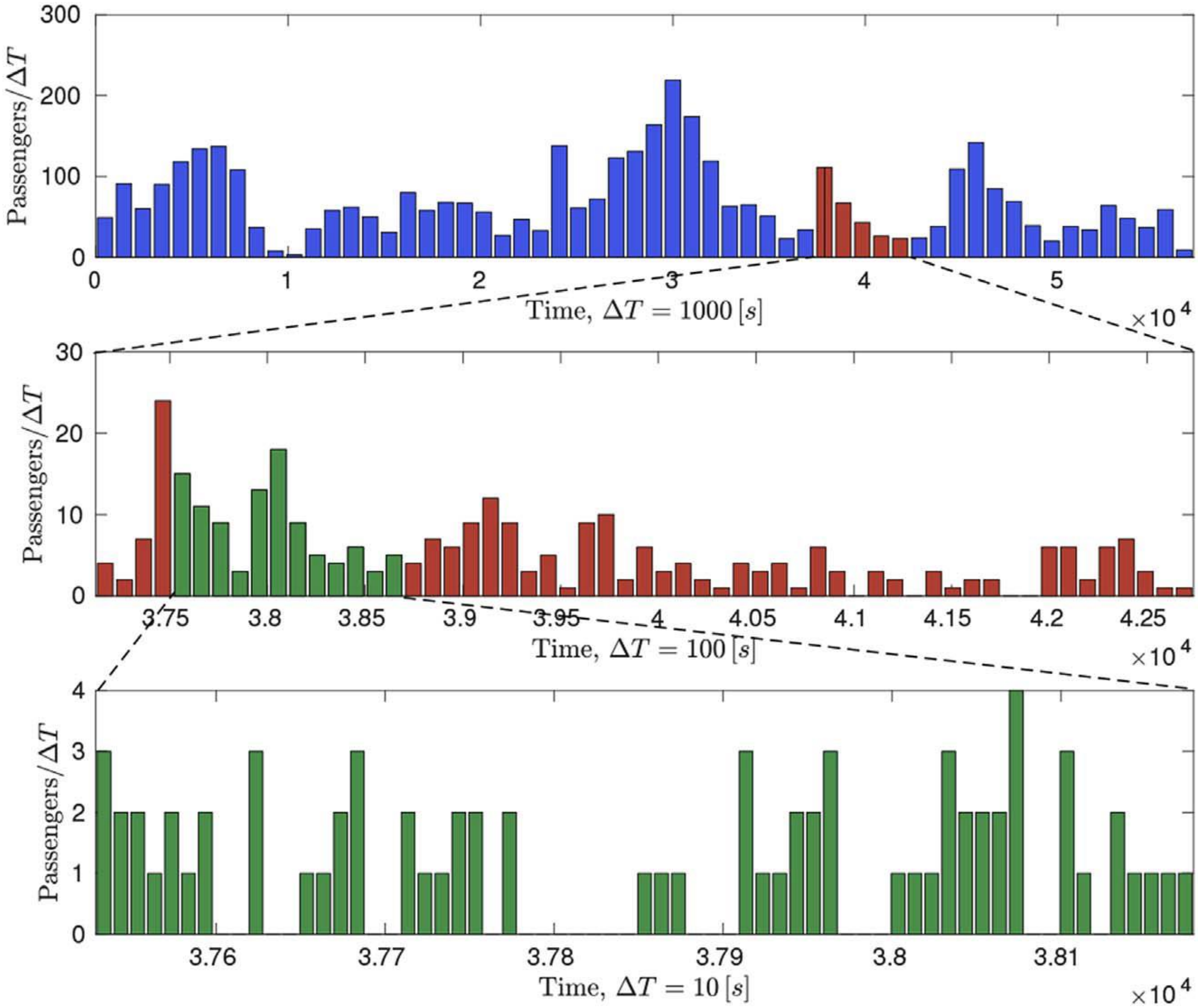

Fig. 3.10. The pictorial "proof" of passenger flow self-similarity. The figure shows the increment process at 3 different time scales, T = {10,100,1000}.

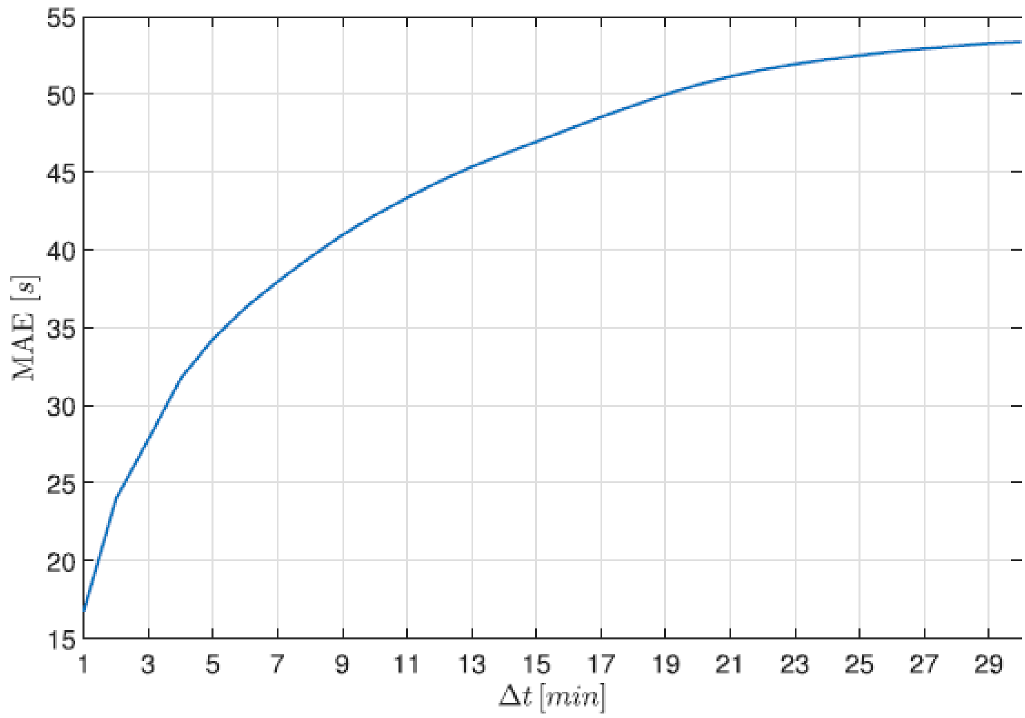

Fig. 3.11. Future waiting times prediction MAE by varying the time shift *t* from 1 to 30[min].

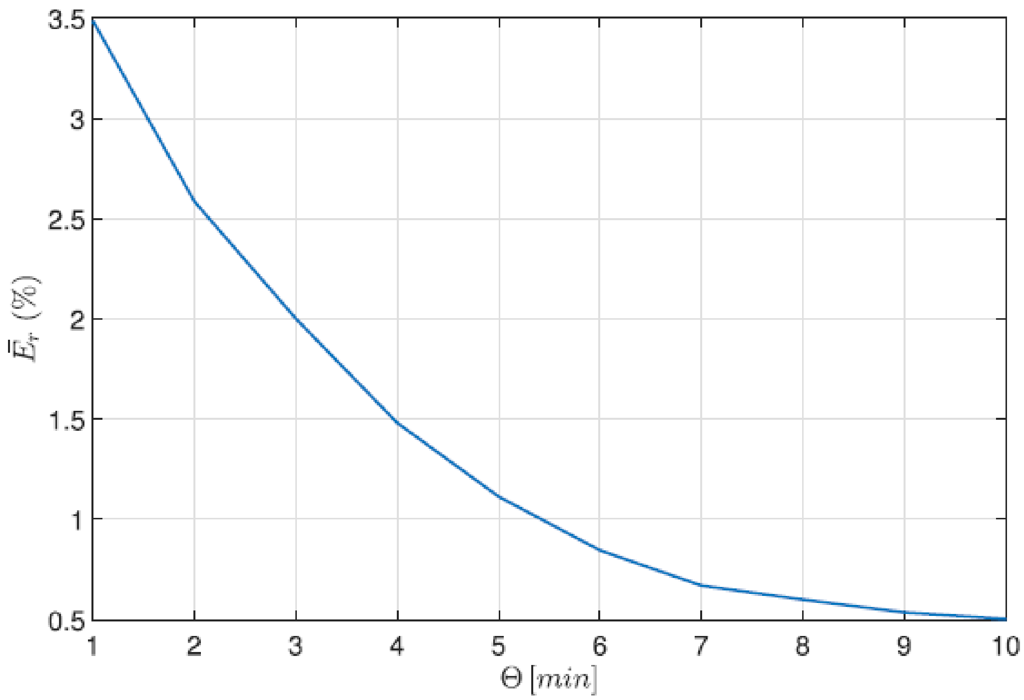

Fig. 3.12. Disposal time predictions performance in terms of the mean relative error E_r by varying threshold Θ from 1 to maximum of 10[min].

Whenever the observed queue state (i.e., number of passengers waiting in line) exceeds L the QCM is activated to derive the suitable c value which guarantees the target service quality according to the CCP sketched in Fig. 3.7.

The AMC model analysis has been performed by varying the threshold Θ from a minimum of 1 min up to a maximum of 10 min. The accuracy of our OCC is validated in Fig. 3.12, where the analytical predictions in terms of T_d are compared with actual data. In can be noticed that the prediction error is, at most, equal to 3.5% for small values of the threshold Θ, since it is likely that Θ could be overcome, due to small fluctuations of passenger flow. Instead, the mean relative error decreases with greater values of Θ.

3.2. An integrated hardware platform for airport queues prediction with application to resources management

Hardware components of the system:

Top VCS sensor

A powerful and simple bi-directional counting device.

The device can be configured using a web browser and send the counting data thought **HTTP.**

Queue sensor

The B--Queue sensors are standard IP video cameras (or Analog).

They are installed above and around the queuing area to have a complete visualization of the area.

The covering area per camera depends on the installation height.

Queue software

The Queue software use an innovative and accurate counting software to determine every minute the number of people present.

ThemulD---camera algorithm can determine precisely the number of people waiting in an area and is able to separate different queuing areas even if they are close to each others.

Blue Count Manager software

The Blue Count Manager gather all the data and save them in its database. Different communication protocols are available to get the data. Its also provide the user dashboard (graphs, tabular views, etc.) and can be personalized if needed.

Server

A server can work with up to 14 Queue sensors (this may vary with the server characteristics). The software can be easily virtualized.

Airport installation of the system (Fig. 3.13). Tasks:

Data gathering (queuing area)

Computation (server room)

Visualization (office)

Display (terminal, mobile)

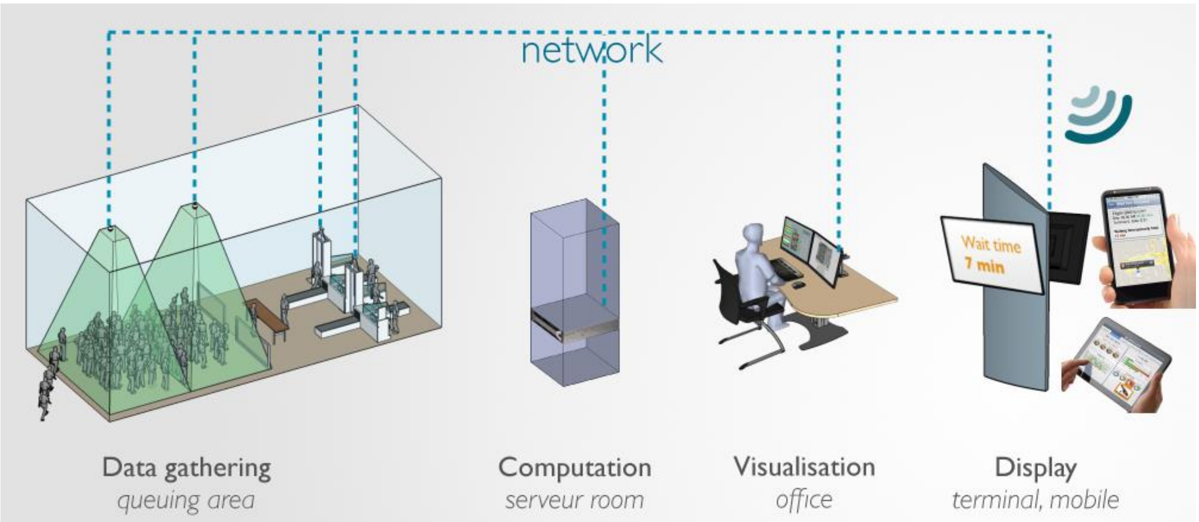

Fig. 3.13. Airport installation

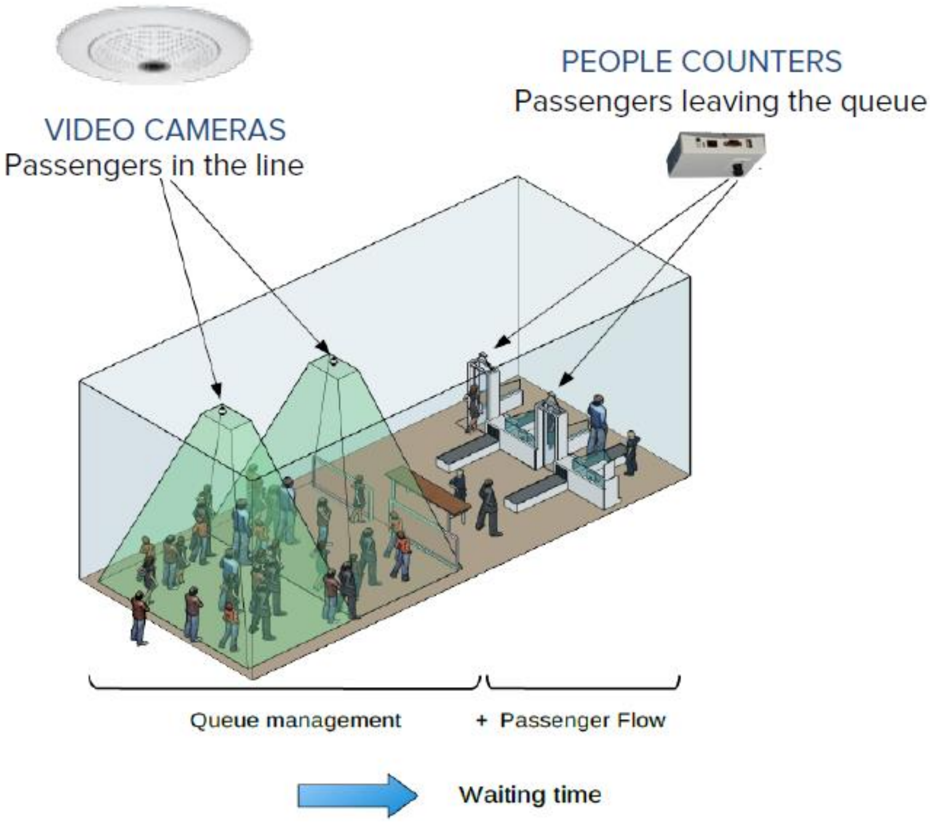

Fig. 3.14. System architecture

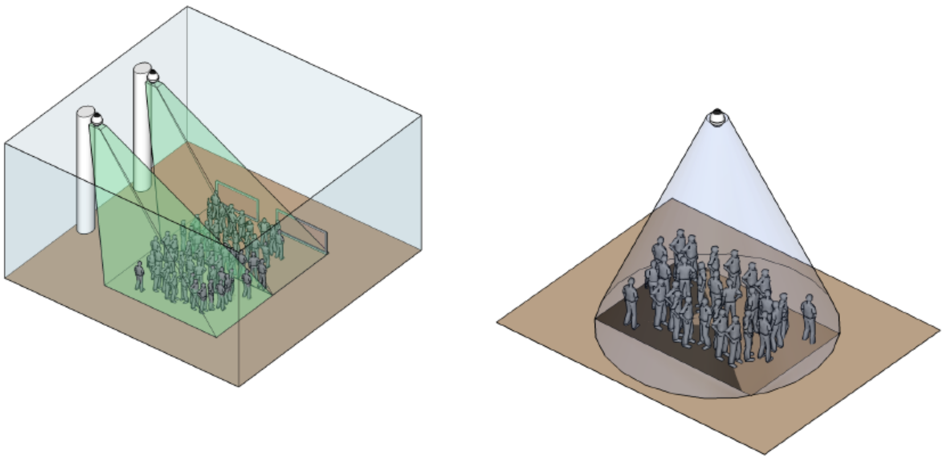

Fig. 3.15. Video sensors

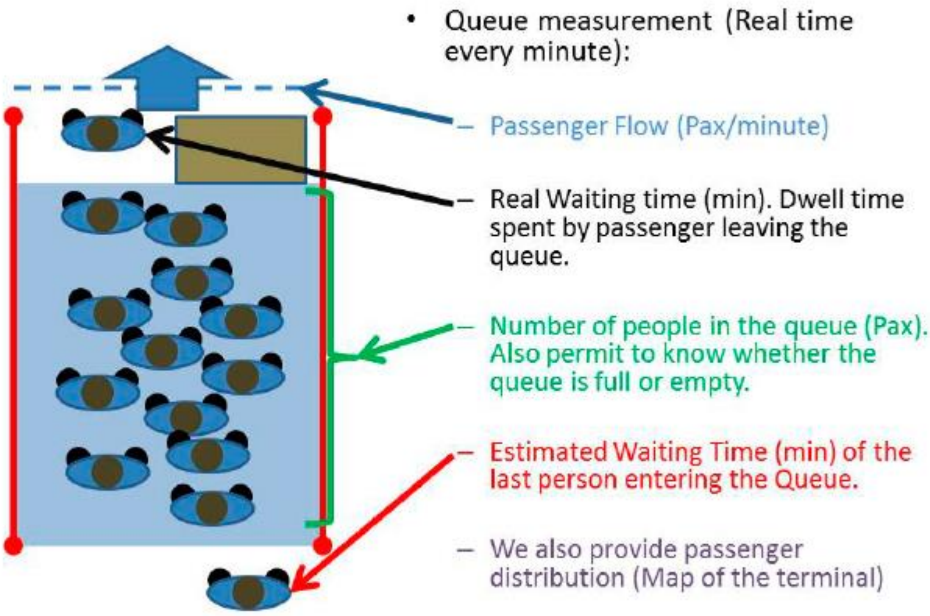

Fig. 3.16. Queue management

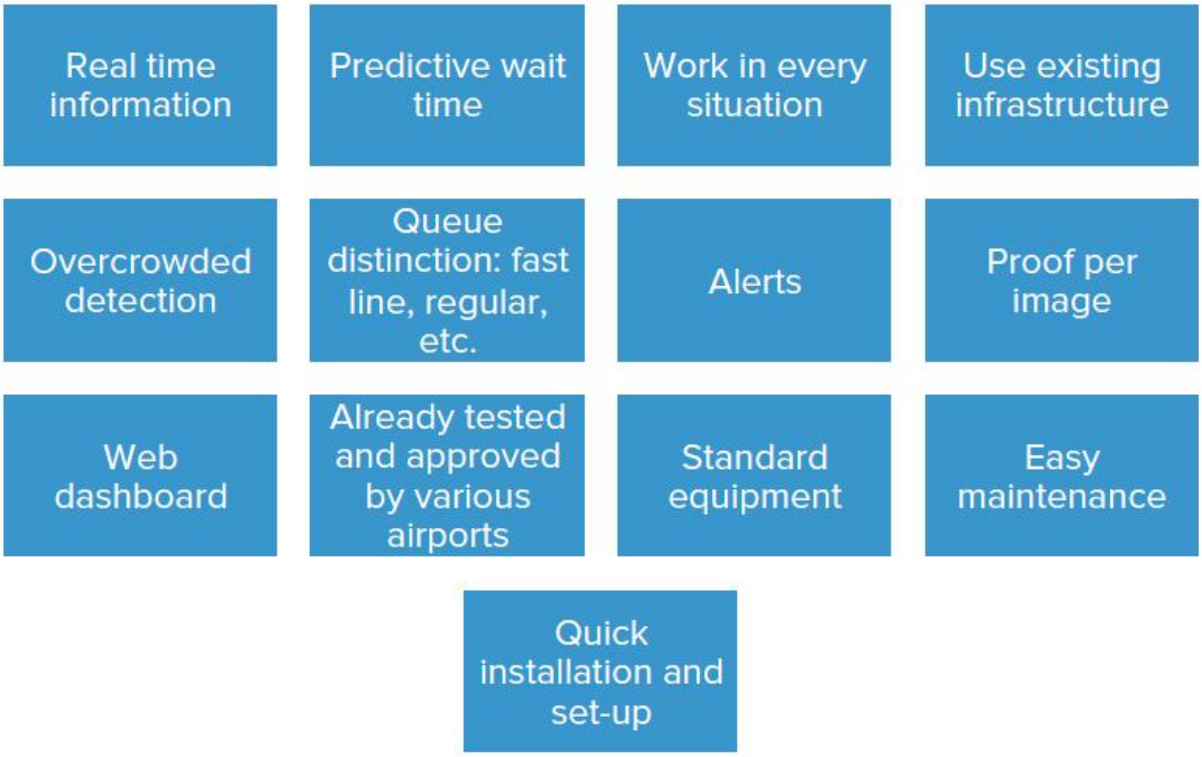

Fig. 3.17. System features

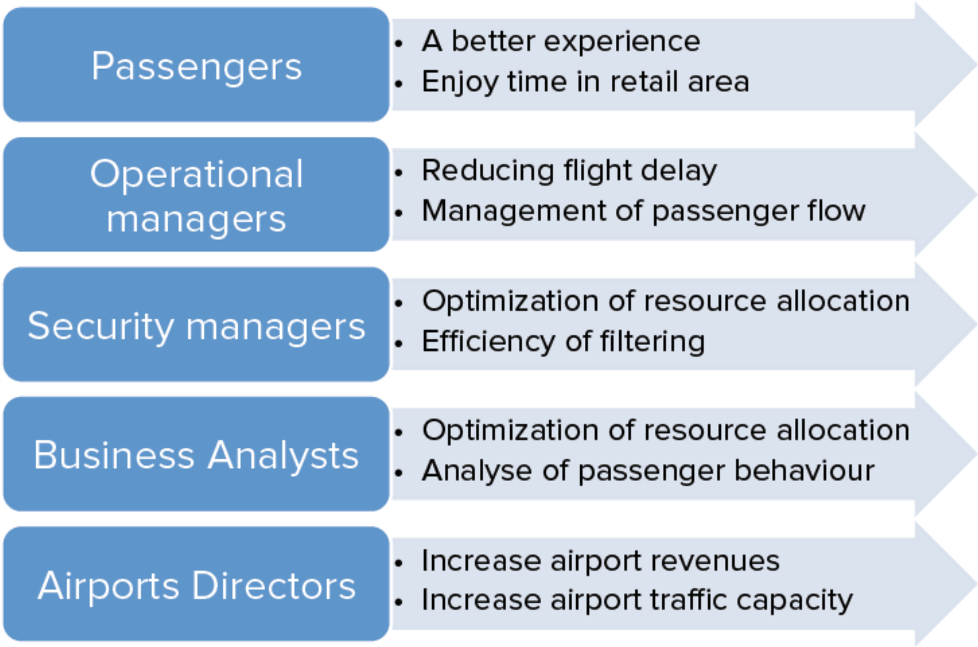

Fig. 3.18. Airport benefits

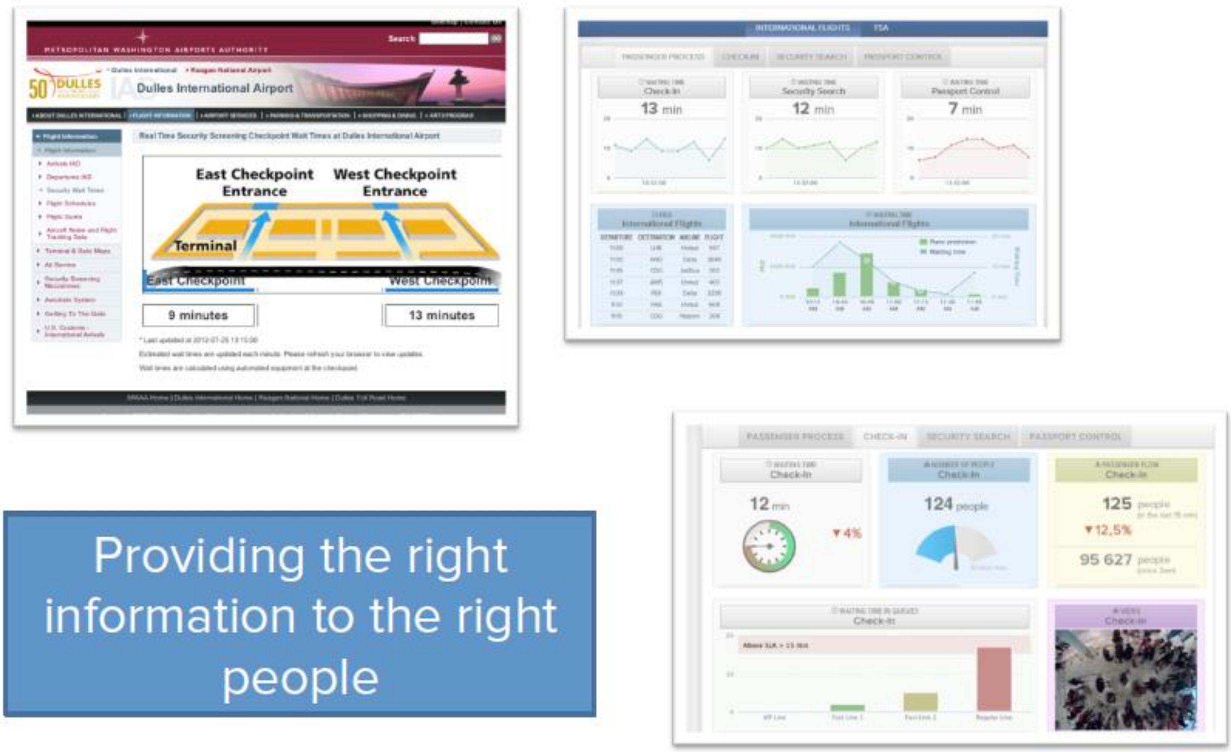

Fig. 3.19. Display on website / application

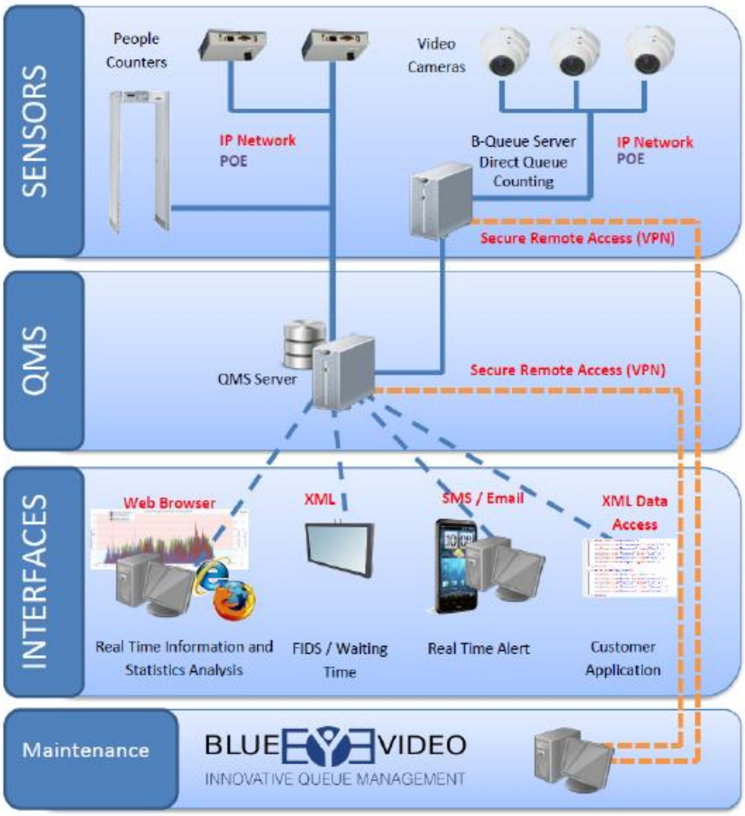

Fig. 3.20. System architecture

3.3. Total costs of development, implementation and technical support of the queue management system

Total costs of the queue management system for airport:

$$C_{\Sigma} = \sum C_{hw} + \sum C_{sw} + \sum C_{m}, \tag{3.16}$$

where: $\sum C_{hw}$ – total costs of hardware development, testing and implementation part of the system; $\sum C_{sw}$ – total costs of software development, testing and implementation part of the system; $\sum C_{m}$ - total maintenance costs.

We propose the system which hardware part consists of:

- 10 queue sensors;
- 1 queue server;
- 6 people counters;
- 1 count management server;
- 10 airport displays;
- 5 computers for system management.

Total hardware costs can be calculated as:

$$\sum C_{hw} = \sum_{k=1}^{l} C_{h\_i} \cdot n_{h\_i} \,, \tag{3.19}$$

where l – total hardware components of the system; C_{h_i} – cost of i-th hardware component of the system; n_{h_i} – number of i-th hardware component of the system.

Eq. 3.19 can be rewrite as:

$$\sum C_{hw} = C_{qsn} \cdot n_{qsn} + C_{qsr} \cdot n_{qsr} + C_{pcn} \cdot n_{pcn} + C_{cms} \cdot n_{cms} + C_{ads} \cdot n_{ads} + C_{csm} \cdot n_{csm} \tag{3.20}$$

Table 3.2

Costs of hardware components

Hardware component	**Count**	**Cost, USD**
queue sensor	10	1200
queue server	1	15000
people counter	6	2500
count management server	1	15000
airport display	10	2000
computer for system management	5	1500

Total hardware costs according to 3.20:

$$\sum C_{hw} = 1200 \cdot 10 + 15000 \cdot 1 + 2500 \cdot 6 + 15000 \cdot 1 + 2000 \cdot 10 + 1500 \cdot 5 = 84500\$$$

The software part of the system consists of:

- Realization of queue management / queue prediction algorithms;
- Realization of network connection protocols between hardware components;
- Realization of sensors protocols / information processing;
- Realization of display / visualization of statistic results;
- Airport mobile application development for passengers.

Total software costs can be calculated as:

$$\sum C_{sw} = \sum_{k=1}^{m} C_{s\_i} \cdot h_{s\_i} \,, \tag{3.21}$$

where m – total software components of the system; C_{s_i} – development rate cost of of i-th software component of the system, in \$ per hour; h_{s_i} – total hours spend of i-th software component of the system.

Eq. 3.21 can be rewrite as:

$$\sum C_{sw} = C_{qmp} \cdot h_{qmp} + C_{ncp} \cdot h_{ncp} + C_{spr} \cdot h_{spr} + C_{dsp} \cdot h_{dsp} + C_{ama} \cdot h_{ama} \quad (3.22)$$

Assume that development cost of hour is average and constant equals to 80 \$/hour

Table 3.3

Total hours spend of software components development

Software component	Total hours	
	min	**max**
Realization of queue management / queue prediction algorithms	700	1000
Realization of network connection protocols between hardware components	100	200
Realization of sensors protocols / information processing	100	200
Realization of display / visualization of statistic results	30	50
Airport mobile application development for passengers	200	400

Total software costs according to 3.22:

$$\sum C_{sw\_\min} = (700 + 100 + 100 + 30 + 200) \cdot 80 = 90400\$$$

$$\sum C_{sw\_\max} = (1000 + 200 + 200 + 50 + 400) \cdot 80 = 148800\$$$

We assume, that total maintenance costs of the system equal from 3% per year (min) of hardware costs to 9% per year (max):

$$\sum C_{m\_y\_\min} = 0{,}03 \sum C_{hw} \quad (3.23)$$

$$\sum C_{m\_y\_\max} = 0{,}09 \sum C_{hw} \quad (3.24)$$

Also we assume that system maintenance costs are uniformly distributed along 12 months (year) period. We consider a 3-year period to calculate total costs of the system.

Define the area of costs of the system for 36 month (3year period) month-per-month which limited by two straight lines – minimum and maximum costs including maintenance costs of the queue management system.

For each *i*-th month the cumulative sum of minimum expenses for the system including month-per-month maintenance costs:

$$TC_{\Sigma\_\min\_i} = \sum C_{sw\_\min} + \sum C_{hw} + \sum C_{mt\_y\_\min\_i} = \sum C_{sw\_\min} + \sum C_{hw} + \frac{0{,}03}{12}\sum C_{hw} \cdot i = \sum C_{sw\_\min} + \sum C_{hw} + 0{,}0025 \cdot i \cdot \sum C_{hw}, \quad (3.25)$$

For each *i*-th month the cumulative sum of maximum expenses for the system including month-per-month maintenance costs:

$$TC_{\Sigma\_\max\_i} = \sum C_{sw\_\max} + \sum C_{hw} + \sum C_{mt\_y\_\max\_i} = \sum C_{sw\_\max} + \sum C_{hw} + \frac{0{,}09}{12}\sum C_{hw} \cdot i = \sum C_{sw\_\max} + \sum C_{hw} + 0{,}0075 \cdot i \cdot \sum C_{hw}, \quad (3.26)$$

where *i* – sequential number of considered month (with 36 month – 3 year period).

The area of costs of the queue management system can be defined using Eq. 3.25 (lower limit) and Eq. 3.26 (upper limit) (Fig. 3.21).

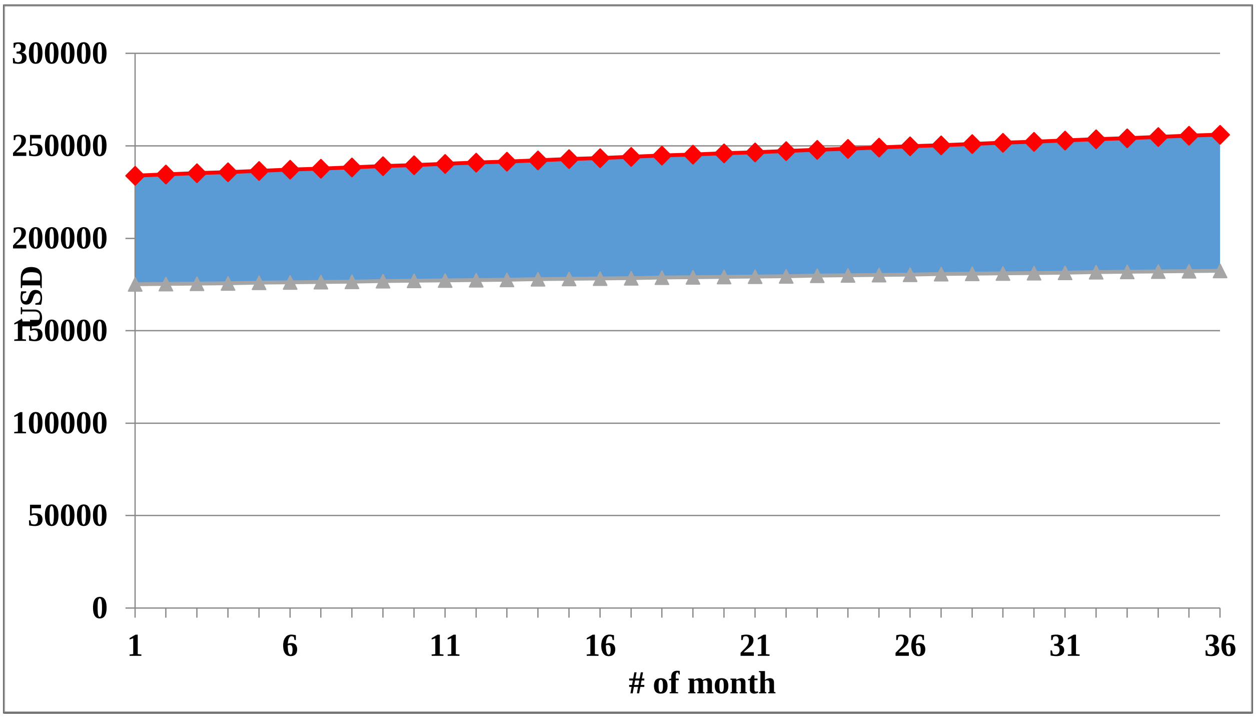

Fig. 3.21. The area of costs of the queue management system

According to graph presented on figure 3.21, the area of costs (blue color) of the queue management system for 36 month period is limited from 175111,3$ (minimal TC, 1 month) to 233933,8$ (maximal TC, 1 month) and from 182505 (minimal TC, 36th month) to 256115$ (maximal TC, 36th month).

This technique can be easily extended to any defined period.

3.4. Implementation the Queue Management System in Morocco Casablanca Mohammed V International Airport for waiting times reducing

We implemented M/M/c queue theory (Poisson Queues) for calculate mean (average) waiting time in each point of checking in Morocco Casablanca Mohammed V International Airport based on actual statistical data.

Server (stations) utilization:

$$\rho = \frac{\lambda}{k \cdot \mu}, \tag{3.27}$$

where λ – arrival rate; μ - service rate; k – number of service stations.

The probability of the system that is idle:

$$P_0 = \left[\sum_{n=0}^{k-1} \left[\left(\frac{1}{n!} \right) \cdot \left(\frac{\lambda}{\mu} \right)^n + \frac{1}{k!} \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu} \right)^k \right] \right]^{-1}. \tag{3.28}$$

Average queue length (average passengers in queue):

$$L_q = \frac{k^k \cdot \rho^{k+1}}{k!(1-\rho)^2} \cdot P_0. \tag{3.29}$$

The number of passengers in the queuing system (average passengers in system):

$$L_s = L_q + k \cdot \rho. \tag{3.30}$$

Average time waiting in line for passenger:

$$W_q = \frac{L_q}{\lambda}. \qquad (3.31)$$

Average time the passenger spent in the queuing system:

$$W_s = \frac{L_s}{\lambda}. \qquad (3.32)$$

We define some average variables based on statistical data and will use some assumptions.

According to statistical data, the Morocco Casablanca Mohammed V International Airport served 9 732 044 passengers in 2018 year. We assume that number of arrive passengers equals to number of departure passengers. We consider only arrive passengers.

Number of arrive passengers in 2018:

9732044/2 = 4866022 passengers.

We assume that even of 4866022 arrive passengers in 2018 has at least 2 companions before arrival. This assumption leads to number of people in airport including visitors:

4866022 x 3 = 14598066 people / 2018 year

On the security station on airport entrance people spend 1 minute in average. Based on this data we can calculate mean (average) arrival rate:

Persons per hour: 14598066 / (365*24) = 1666,45 persons / hour = 27,78 persons / minute

Average queue length if we have *one security station* (see Eq. 3.31):

L_q = 1 minute x 27,78 persons / minute = 27,78 persons

Average service rate for *single security station:*

μ = 28.7464 persons / minute

Obviously, this value is too high. That is why we proposed to install additional security stations for some peak hours. Here we consider 2 variants and make assumptions for each of them.

Variant 1. We assume that *average* service time will be the same for each station. Let us consider how many stations should be installed and how *average* service rate should be for: 1) reduce waiting time twice; 2) waiting time tends to 0 (less than 5 seconds).

Variant 2. We assume that number of security stations is equal 2 and passenger flow divided into two parts – departure passengers and visitors / companions. Also we assume that number of visitors of the airport is 2 or more times greater than number of passengers and *average* service rate in security station for visitors is 2 times higher than in security station for passengers. These 2 stations are independent. Let us consider average service rate for each station for: 1) reduce waiting time twice; 2) waiting time tends to 0 (less than 3 seconds).

Variant 1.

Table 3.4.

Number of stations and *average* service rate for reduce waiting time twice (to 30 seconds)

# of stations	Mean (average) arrival rate, passengers / minute	Average service rate, passengers / minute	L (Average Customers in System)	L_q (Average Customers in Queue)
2	27,78	14.8	15.7479	13.8709
3	27,78	9.85	16.7724	13.952
4	27,78	7.38	17.6943	13.93
5	27,78	5.895	18.808	14.0955

Table 3.5.

Number of stations and *average* service rate for waiting time tends to 0 (less than 3 seconds)

# of stations	Mean (average) arrival rate, passengers / minute	Average service rate, passengers / minute	*L* (Average Customers in System)	L_q (Average Customers in Queue)
2	27,78	20.5	2.5053	1.1501
3	27,78	13.8	2.9321	0.919
4	27,78	9.75	3.9583	1.1091
5	27,78	8.43	3.9054	0.61

Variant 2.

If passenger flow divided into two parts – departure passengers and visitors / companions and number of visitors of the airport is 2 or more times greater than number of passengers them number of passengers:

14598066 / 3 = 4866022 passengers

Number of visitors / companions:

4866022 x 2 = 9732044 companions

than arrival rate for passengers:

4866022 / (365*24) = 555,5 passengers / day

and for companions:

9732044 / (365*24) = 1110,97 visitors / day

Average service rate in security station for visitors (companions) is 3 times higher than in security station for passengers.

Let us consider average service rates for each station for: 1) reduce waiting time twice; 2) waiting time tends to 0 (less than 3 seconds).

Table 3.6.

Average service rates for reduce waiting time twice (to 30 seconds) for 2 stations with different arrival/service rates

# of stations	Average arrival rate, passengers / minute for 1st station	Average arrival rate, passengers / minute for 2nd station	Average service rate for 1st station, passengers / minute	Average service rate for 2nd station, passengers / minute	*L* (Average Customers in System) for 1st station	*L* (Average Customers in System) for 2nd station	L_q (Average Customers in Queue) for 1st station	L_q (Average Customers in Queue) for 2nd station
2	0.3857	0.7715	1.09	1.68	0.5478	0.8492	0.1939	0.39

Table 3.7.

Average service rates for waiting time tends to 0 (less than 3 seconds) for 2 stations with different arrival/service rates

# of stations	Average arrival rate, passengers / minute for 1st station	Average arrival rate, passengers / minute for 2nd station	Average service rate for 1st station, passengers / minute	Average service rate for 2nd station, passengers / minute	*L* (Average Customers in System) for 1st station	*L* (Average Customers in System) for 2nd station	L_q (Average Customers in Queue) for 1st station	L_q (Average Customers in Queue) for 2nd station
2	0.3857	0.7715	3.1	4.44	0.1476	0.2103	0.019	0.0365

As we can see, for 2 divided flows and two different stations for the first station with *average* arrival rate 0,3857 passengers / minute we should provide *average* service time not less than 3,1 passengers / minute and for second station with *average* arrival rate 0,7715 passengers / minute we should provide *average* service time not less than 4,44 passengers / minute for preventing queues.

CONCLUSIONS

Air Transportation Management Department				NAU 20. 09. 46. 400EN					
Done by	Maghraoui M			CONCLUSIONS	Letter			Sheet	Sheets
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Theoretical findings of development, implementation and technical support of the queuing management system and application for Morocco Casablanca Mohammed V International Airport have been performed. It was found that integration Queue management and prediction system with AR system can drastically reduce average service time and therefore reduce average passengers waiting time in queues. This research proposes an integrated and flexible service hardware and software platform suitable for airport operations management. In designing the software architecture, a modular approach has been adopted, where each module is devoted to a specific management and control function. In particular, the focus has been on the security checkpoint operations that represent the main critical activities both for passengers and for Airport operators point of views. Towards this goal, a specific module has been characterized, named QCM, whose procedures are based on the M/M/c queueing analytical model. The accuracy of the proposed approach has been validated by a statistical analysis of data collected in the airport, pointing out the appropriateness of the model. In addition to this, the effectiveness of the proposed estimation algorithms has been shown by comparing the analytical predictions with actual data retrieved by a measuring campaign carried out in an airport environment. Finally, the obtained results highlight the effectiveness of the QCM in order to achieve an efficient resource airport management and improve the passengers Quality of Experience.

According to the calculation performed for 2 divided flows and two different stations for the first station with *average* arrival rate 0,3857 passengers / minute we should provide *average* service time not less than 3,1 passengers / minute and for second station with *average* arrival rate 0,7715 passengers / minute we should provide *average* service time not less than 4,44 passengers / minute for preventing queues.

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